

DOCKET NO. **SA- 516**

EXHIBIT NO. **12-B**

**NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D.C**

**GROUP CHAIRMAN'S FACTUAL
REPORT OF INVESTIGATION
SOUND SPECTRUM STUDY**

National Transportation Safety Board
Office of Research and Engineering
Washington, D.C. 20594

November 15, 1997

Group Chairman's Factual Report of Investigation

Sound Spectrum Study

Cockpit Voice Recorder

DCA-96-MA-070

A. ACCIDENT

Location: East Moriches, New York
Date: July 17, 1996
Time: 2031:12 Eastern Daylight Time
Aircraft: Trans World Airlines Inc.
Boeing 747-131 N93119

B. GROUP

Chairman: James R. Cash
Electronics Engineer
National Transportation Safety Board

Member: Donald W. Boston
Senior Principle Engineer
Boeing Commercial Aircraft Co.

Member: James Ryan
Supervising Special Agent
Federal Bureau of Investigation

Member: Terry Stacey
747 Flight Standards Manager
TWA Inc.

Member: Mehmet Marsan
Acoustics Engineer
Federal Aviation Administration

Member: Al Weaver
Accident Investigator
Pratt&Whitney Aircraft

Member: James Walters
Captain
Airline Pilots Association

Member: Pete Sheppard
Asst. Principle Inspector
AAIB (UK)

C. SUMMARY

A Fairchild model A-100 cockpit voice recorder (CVR) s/n UNK was brought to the audio laboratory of the National Transportation Safety Board. The good quality 31½ minute recording was examined to document any abnormal or unusual occurrences.

D. DETAILS OF INVESTIGATION

The CVR recording recovered from the accident aircraft consisted of 4 channels of good quality continuous audio. One channel contained audio information obtained from the cockpit area microphone located in the cockpit of the aircraft. The other three channels contained audio information obtained from the Captain's, the First Officer's, and the Second Officer's radio/intercom selector panels.

The audio information found on the cockpit area microphone channel of the recording is sound and vibration information picked up by the fuselage mounted microphone. This microphone is operating any time there is electrical power to the cockpit voice recorder. The cockpit microphone is designed to respond to audio (airborne) sounds, but it also responds to some vibration stimulus that is transmitted through the fuselage to the structure mounted microphone.

The audio information that is recorded on the 3 crew members radio/intercom channels is determined by the individual selections on the 3 respective audio selector panels. The CVR records whatever the crew had selected and was listening to in their headsets. The volume of the audio information is proportional to the

loudness of the setting that the crew made. In this model Boeing 747 aircraft the audio information recorded would consist of air-to-ground communication and navigation radio audio information. This aircraft was not equipped with individual "hot" crew boom microphones nor was it required to be. If the aircraft had a "hot" boom microphone installation, the CVR would have directly record the individual crew's conversations and sounds in the cockpit in addition to the information from the aircraft's radios.

The recording was examined to document any unusual or abnormal occurrences. During the development of the transcript of the recording, the CVR group identified two segments of the recording that needed further examination. Both of these segments were contained in the last several seconds of the recording. One of these segments was approximately 0.73 seconds from the end of the recording. An abnormality was identified as a change in the background 400 Hz. aircraft's electrical system hum as recorded by the CVR. The second segment that was identified was the last few tenths of a second of the recording. The recording appeared to terminate very abruptly with a very loud sound. This termination did not appear to be preceded by any event or events on the recording. Both of these areas were the subject of further examination.

The audio information from the four channels was examined to document any sounds or electrical disturbances recorded on the CVR. The recording was examined on a spectrum analyzer which gives a visual presentation of the frequency content of the signals. The information was also examined using a computer signal analyzer. This computer program allows detailed analyses of both the analog wave form and frequency content as well as providing detailed timing information of the events.

Electrical System "Hum" Abnormality

The event identified was found on the captain's channel of the CVR. This channel in addition to the other 2 radio channels of the CVR for most of the recording contained very little audio information. These channels were only active when the aircraft was receiving or transmitting on the air-to-ground radios. Most of the time the channels were quiet and contained

only nominal background noise. This background noise consisted primarily of the 400 Hz. aircraft electrical system power "hum". In addition to this predominant 400 Hz. frequency there was additional signals consisting of the 2nd (800 Hz.) and 3rd (1200 Hz.) harmonic tones of the primary 400 Hz.

At time 0.73 seconds before the end of the recording and again at 0.68 seconds before the end, the normal 400 Hz signal with its associated harmonics changed. Chart 1 depicts this change in the background signal as observed on the Captain's radio channel. This change consists primarily of a lack of the upper harmonics of the 400 Hz. During these two different areas the signal contains only the 400 Hz component, no added harmonics. Chart 2 depicts the Captain's radio channel and the frequency plots for the regions prior, during and after the disturbance. Chart 3 depicts all of the 3 radio channels in this same area. It can be seen that the disturbance is identifiable only on the Captain's radio track of the CVR.

The last 15 minutes of the recording was examined in an attempt to document any additional or similar power disturbances. None could be found.

Termination of the Recording:

The CVR recording was for the most part very routine and normal until it abruptly ended. This sudden termination of the recording affected all 4 of the CVR channels. Chart 4 depicts the 4 CVR channels for about the last second of CVR data. The top trace displays the data from the 1st Officers radio/intercom channel. The 2nd trace is the data from cockpit area microphone channel. The 3rd trace is the data from the Captain's radio/intercom channel. The 4th trace depicts the information from the 2nd Officer's radio/intercom channel.

It can be seen from chart 4 that the termination of the recording affected all of the channels slightly differently. It could be assumed that the termination event should look the same on the 3 radio channels. These 3 channels all are identical in their function and they are all being fed information obtained from identical sources. It can be seen on the chart that trace 3 (Captain's radio) is affected 7.25 microseconds

before any disturbance is observed on the other radio channels.

Charts 5,6,and 7 show in greater detail the relationships between the various radio channels and the corresponding area microphone channel. Chart 5 is the 1st Officers radio on the top and the area microphone channel below it. Chart 6 depicts the Captain's radio and area mike information and chart 7 depicts the 2nd Officers and area mike information.

To further our understanding of how the cockpit voice recorder responds during in-flight explosions and break-ups several CVR recordings were obtained for comparison purposes. These comparison recordings were plotted in a similar way as the accident recording. Chart 8 depicts the 4 CVR channels obtained from the PanAm Lockerbee accident involving a Boeing 747-100 aircraft. Chart 9 depicts the CVR record of the in-flight accident of a Air India Boeing 747-100. Chart 10 depicts the CVR information obtained from a United Boeing 747-100 in-flight loss of the forward cargo door. Chart 11 depicts the CVR record obtained from a center wing fuel tank explosion onboard a Philippine Airlines Boeing 737-400 aircraft that was being pushed back from the gate.

In Charts 8,9,10,11 and in the accident chart (4) it can be seen that in all of flights not only is the disturbance observed on the cockpit area microphone (CAM) channel but a similar disturbance is also observed on all of the radio channels. These disturbance patterns were examined in an attempt to associate the accident flight's CVR signatures with a previous recording.

The actual sound signatures that were recorded on the CAM channels of the various CVR's were also looked at as another means of comparing the various recordings. The sound signatures were examined by comparing: 1. the waveform amplitude signature, 2. The frequency spectrum profile or signature, 3. The total spectral energy vs. time profile or signature.

Chart 12 depicts the waveform amplitude signatures of the various comparison accidents along with the TWA-800 accident recording. This chart depicts the various waveform amplitudes vs. time. It should be noted that the absolute amplitude of the various recordings is unknown. Care should be used when attempting to compare waveform characteristics based only on the amplitude.

Charts 13,14,15,16 and 17 depict the area mike recordings and their associated frequency spectrum signatures. In these charts the top trace is the analog waveform plot and the bottom trace is a 3-dimensional frequency spectrum plot. This type of chart presents frequency along the vertical axis, time along the horizontal and spectral intensity or energy in the color information.

Charts 18,19,20,21, and 22 depict the area microphone channel and the associated energy or power distribution. These charts show the waveform of the area microphone channel on the top chart along with the energy on the bottom chart. The energy chart displays the total energy or power of the signal on the vertical axis and how it is distributed over time (horizontal axis).

Aircraft Testing:

In addition to using accident recordings the Safety Board conducted several controlled experiments to document how the cockpit voice recorder system as installed on a Boeing 747 aircraft responds to various types of explosive events. To conduct these experiments, the Safety Board obtained the use of an old decommissioned Boeing 747-100 series aircraft¹. The aircraft was structurally intact, resting on its own landing gear. It had all of the exterior doors and windows and was capable of being pressurized. The engines and the interior of the aircraft had been removed. The cockpit structure was intact but the flight instruments and instrument panels had been removed. For the tests the aircraft² was outfitted with several test voice recorders and additional instrumentation. One of the voice recorders that was used attempted to duplicated the same area microphone and recorder that was installed on the accident aircraft.

The tests were conducted in 3 phases. The first phase was used to obtain basic information on how the CVR recording system responds to controlled high explosive detonations at various locations inside and outside of the Boeing 747 fuselage. Phase 2 consisted of the detonation of 4 simultaneous explosions in 4 different cargo container locations onboard the pressurized aircraft. The information from this test was recorded utilizing the same CVR setup and instrumentation as from the Phase-1 test. The third and final phase was conducted to document how the aircraft and CVR system respond to fuel-air explosions at various location onboard of the aircraft. In all over 60 separate tests were conducted at various aircraft locations, charge size, charge placement, and type of explosion used. In addition to the small controlled tests, one full scale test was conducted by exploding the center wing tank (CWT) of the test aircraft with a known fuel-air mixture. All of these tests were recorded by the various CVR system that we installed on

¹ The aircraft was obtained by the Federal Aviation Administration and the British Civil Aeronautic Administration to conduct aircraft hardening trials on cargo containers. The Safety Board's experiments were conducted prior to (Phase-1) and after (Phase-3) the hardening trial (Phase-2).

² For additional information on the Safety Board test refer to the DERA report titled Phase-1 Trial documentation dated August 1997.

the aircraft. In addition to the CVR recordings, the aircraft was outfitted with various instrumentation sensors which were also recorded. These sensors included: multi-axis accelerometers at several cabin/cockpit locations, pressure sensors in the cockpit and in the cabin, flash or detonation sensors, cabin and cockpit audio microphones, and a UHF radio sensor. During the center wing tank experiment additional instrumentation was added to record the acceleration, the pressures, and the gas mixture inside of the tank. Photographic and or video records were also made during selected tests.

High Explosive Tests Phase-1:

Selected plots from the trials were used as a comparison with the accident recording. Chart 23 depicts some of the data obtained from Phase-1 test 6. This test was conducted by exploding a small high explosive device suspended from the ceiling of the aircraft in the cabin over the center fuselage tank area. In the chart the individual traces are as follows: Trace 1 is the T_0 sensor which shows the time of detonation. Trace 2 is data obtained by a pressure sensor mounted in the cockpit. Trace 3 is data as measured by an accelerometer mounted to the aircraft structure in the cockpit. Trace 4 is the data as measured by an accelerometer mounted to the skin of the aircraft below the cockpit. Trace 5 shows the information recorded by a Fairchild model A-100A cockpit voice recorder. Trace 6 is the information recorded by the identical model Fairchild A-100 cockpit voice recorder as installed on the TWA-800 aircraft. To assist in a comparison of the data Charts 24 and 25 were included. Chart 24 depicts the same data from a test where the same size explosive was placed almost underneath of the cockpit (aircraft station 420). Chart 25 is the same information from a test where the same charge size was placed as far aft in the cabin as was possible (aircraft station 2220).

Fuel-Air Tests Phase-3:

Similar information was obtained on how the aircraft and the CVR recording system responded to a fuel-air type of explosion. Test data was collected by exploding a controlled fuel-air (1:5 mixture of propane and oxygen) mixture at various location in the cabin of the aircraft. The data was collected on

identical CVR systems and instrumentation as in the previous tests. Chart 26 depicts the data corresponding to a fuel-air test where the charge was located in the forward cabin directly below the cockpit (aircraft station 420). Chart 27 depicts the data obtained from a test where the charge was located in the mid-section of the aircraft over the fuselage center fuel tank (aircraft station 1380).

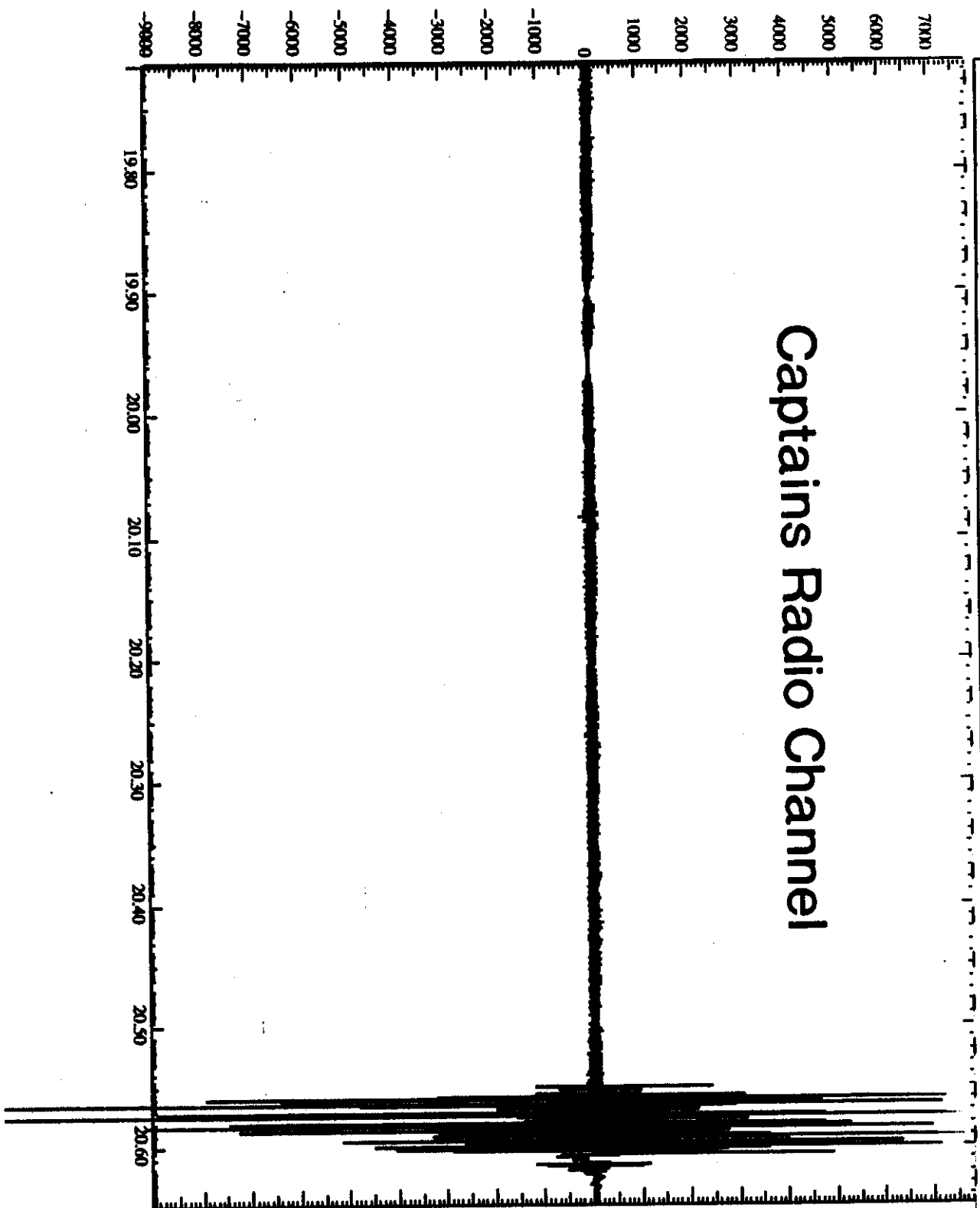
The final test in the trial was to explode a fuel-air mixture in the center wing fuel tank of the Boeing 747 aircraft. This test was conducted by injecting propane into the center wing tank to obtain a 3.2% propane/air mixture. The tank was ignited by placing a small high explosive device on the rear spar of the aircraft. The same CVR recorders and instrumentation were used to document the tank explosion. Chart 28 depicts the same 6 traces which represent the charge initiation (T_0), cockpit pressure, cockpit acceleration, cabin acceleration, Fairchild A-100A CVR, Fairchild A-100 CVR. Chart 29 depicts an expanded trace of the Fairchild A-100 CVR record and chart 30 depicts an expanded trace of the Fairchild A-100A CVR. Chart 31 depicts the sound data from the Fairchild A-100 CVR in addition to the power/energy distribution plot similar to what was shown on charts 18-22.

James R. Cash
James R. Cash
Electronics Engineer

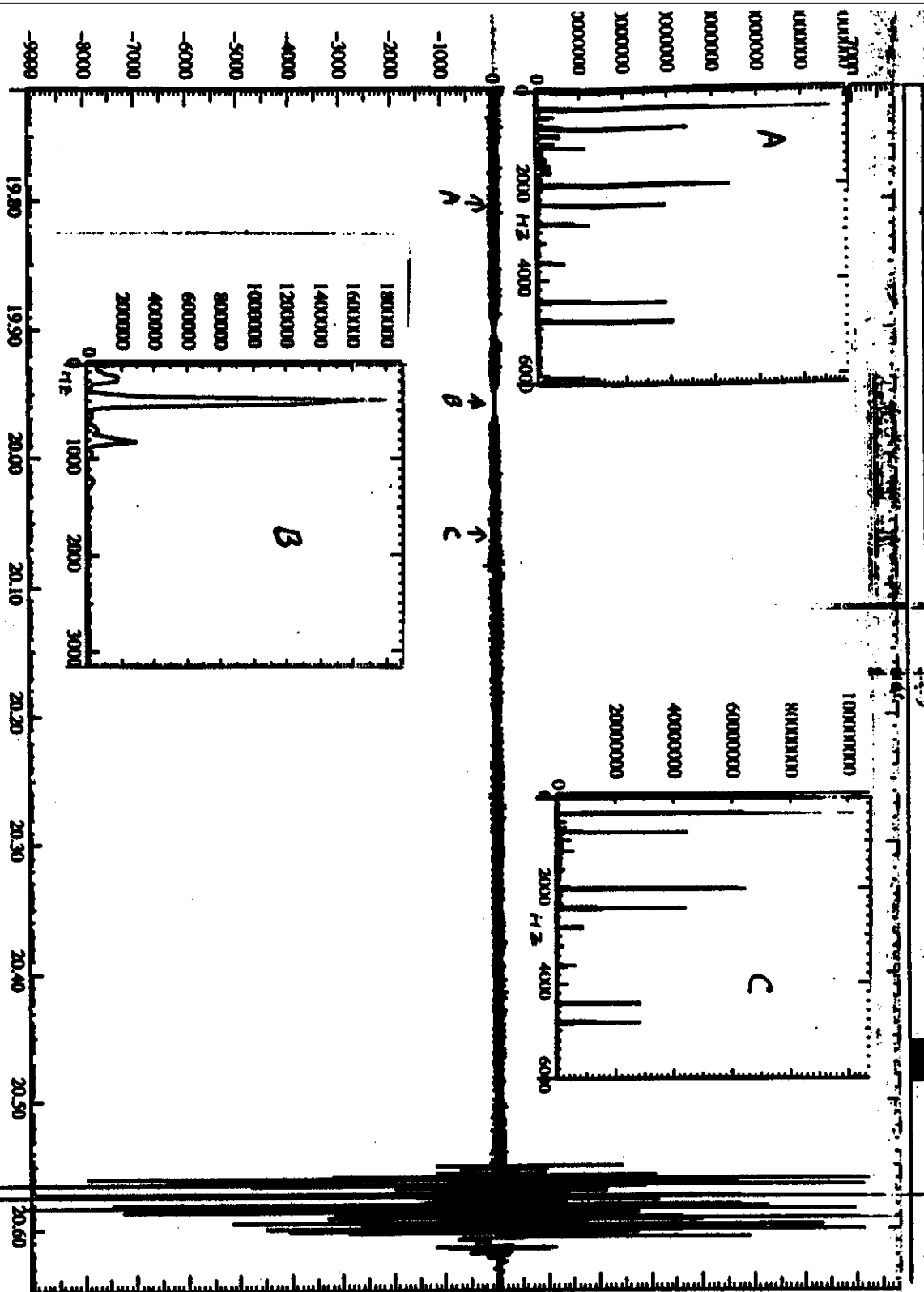
Time: 10.7138Sec

0.00000 Hz 10.71385 R: 19.71385 (F:)

Captains Radio Channel



DJANGO L 19.7135 R 19.7135 (E)



Captains Radio Channel

Time: 19.71385sec

D: 0.00000 L: 19.71385 R: 19.71385 (F: ———)

Captain's Radio Channel

19.80 Time: 19.71385sec 20.00 20.10 D: 0.00000 L: 19.71385 R: 19.71385 (F: ———) 20.50 20.60

1st Officer's Radio Channel

19.80 Time: 19.71385sec 20.00 20.10 D: 0.00000 L: 19.71385 R: 19.71385 (F: ———) 20.50 20.60

2nd Officer's Radio Channel

19.80 19.90 20.00 20.10 20.20 20.30 20.40 20.50 20.60

Time: 18.00050sec

17.999670 L: 17.99670 R: 17.99670 (F: 17.99670)

1st Officer's Radio Channel

Time: 18.00050sec

17.999670 L: 17.99670 R: 17.99670 (F: 17.99670)

Cockpit Area Mike Channel

Time: 18.00050sec

17.999670 L: 17.99670 R: 17.99670 (F: 17.99670)

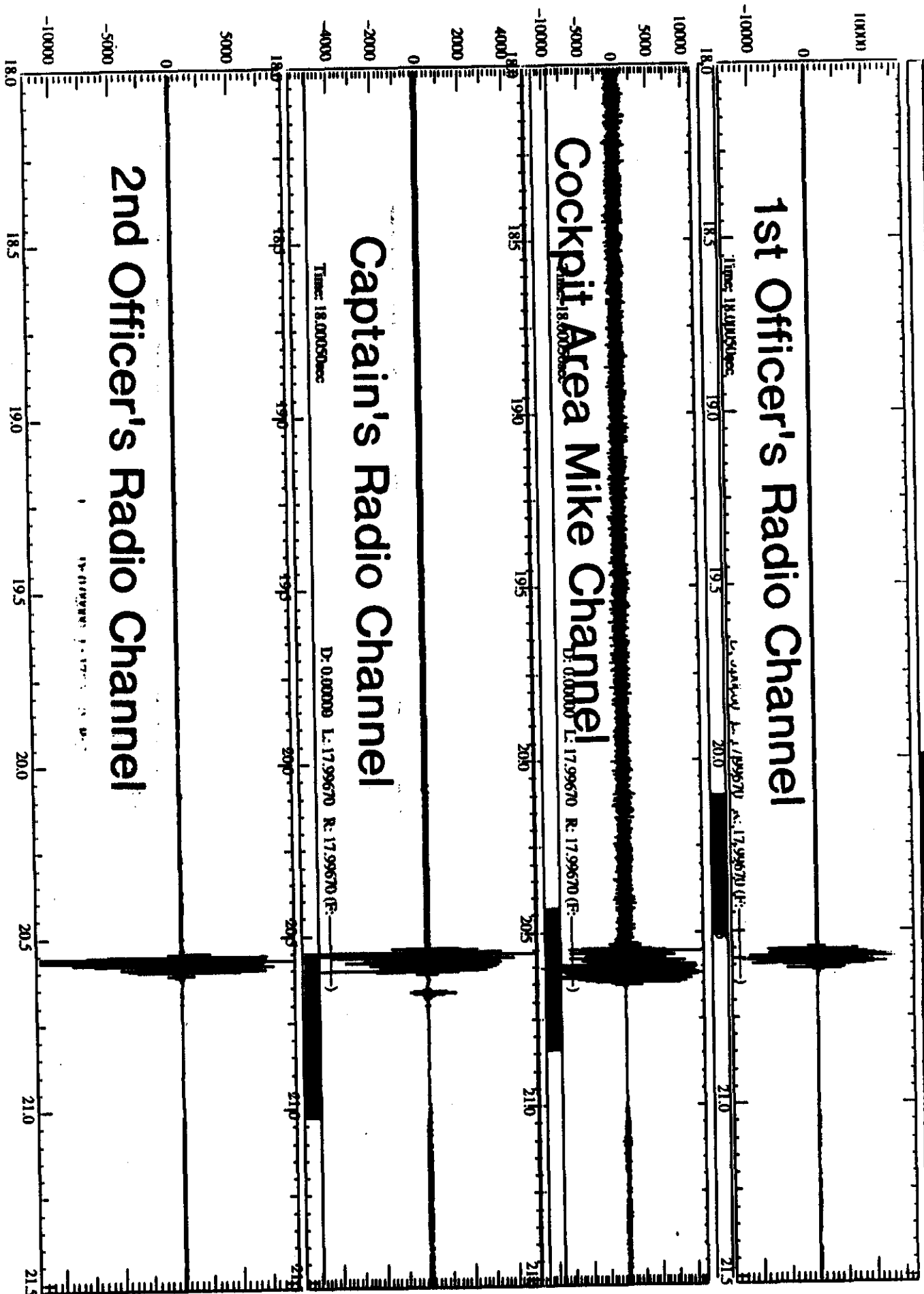
Captain's Radio Channel

Time: 18.00050sec

17.999670 L: 17.99670 R: 17.99670 (F: 17.99670)

2nd Officer's Radio Channel

Time: 18.00050sec



Time: 20.40050sec

D: 0.70245 L: 20.40050 R: 21.10295 (F: 1.42)

1st Officers Radio Channel

20.50 Time: 20.40050sec 20.60

20.70

D: 0.70245 L: 20.40050 R: 21.10295 (F: 20.802)

21.00

21.10

Cockpit Area Mike Channel

20.50

20.60

20.70

20.80

20.90

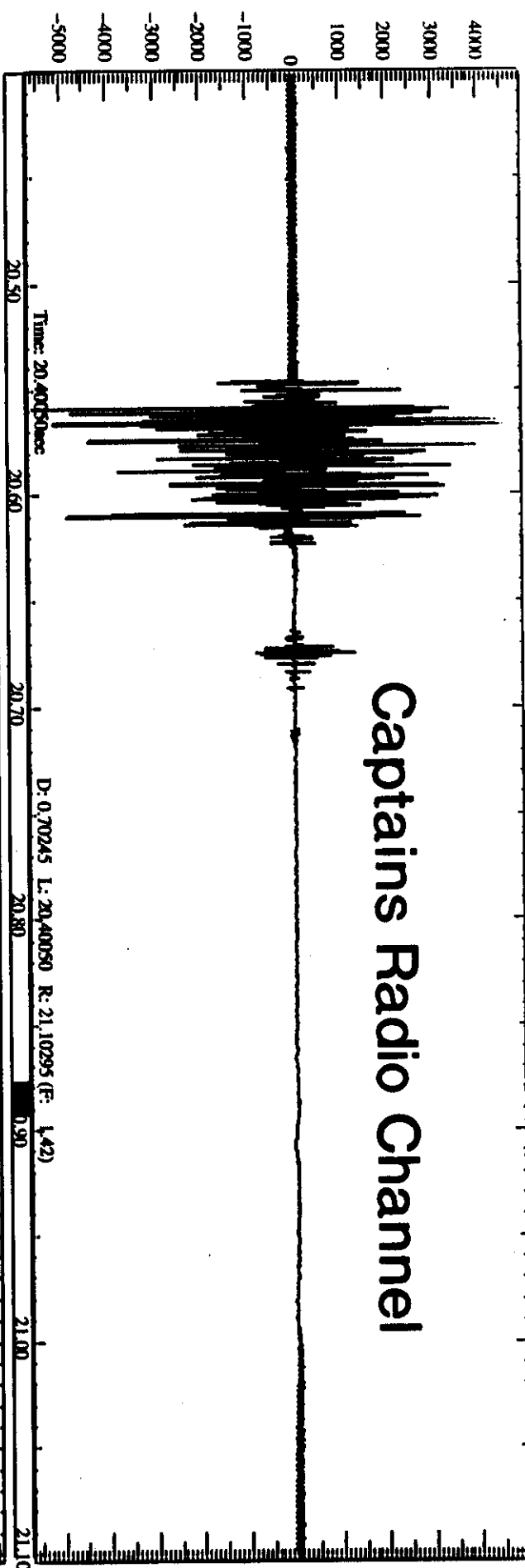
21.00

Chart 5

Time: 20.40154sec

D: 0.70245 L: 20.40050 R: 21.10295 (F: 1.42)

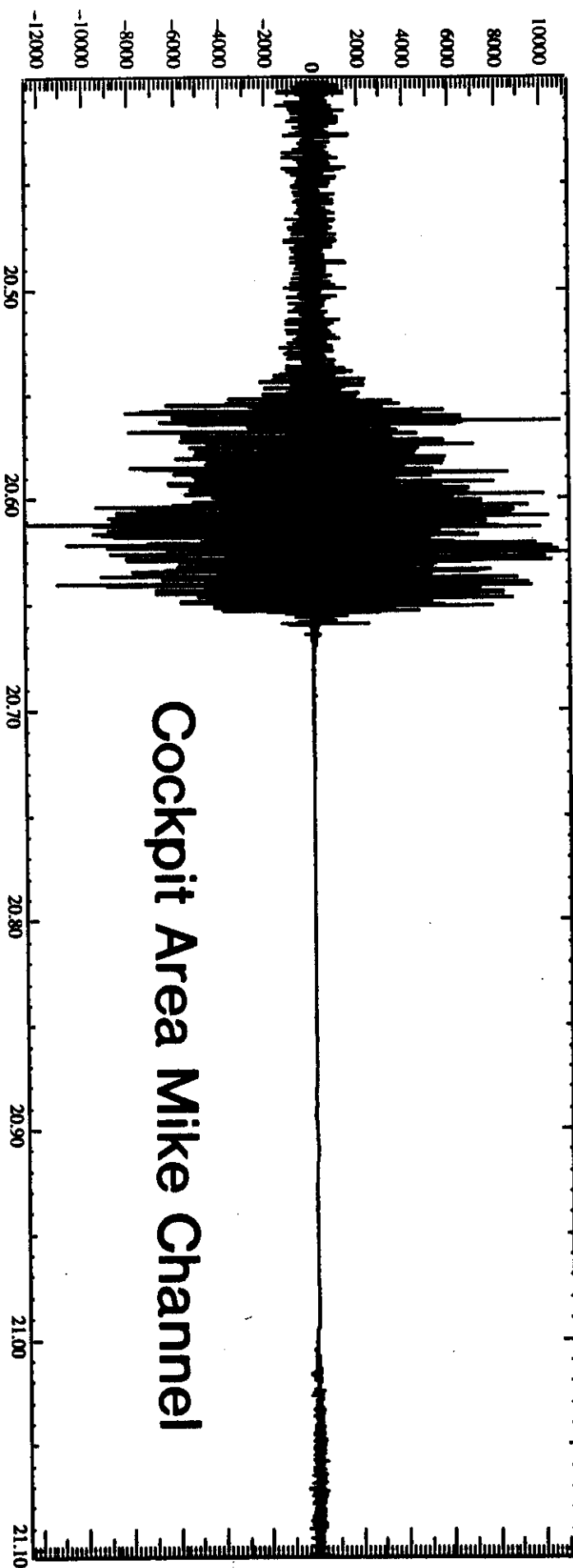
Captains Radio Channel



Time: 20.40050sec

D: 0.70245 L: 20.40050 R: 21.10295 (F: 1.42)

Cockpit Area Mike Channel



Time: 20.40050sec

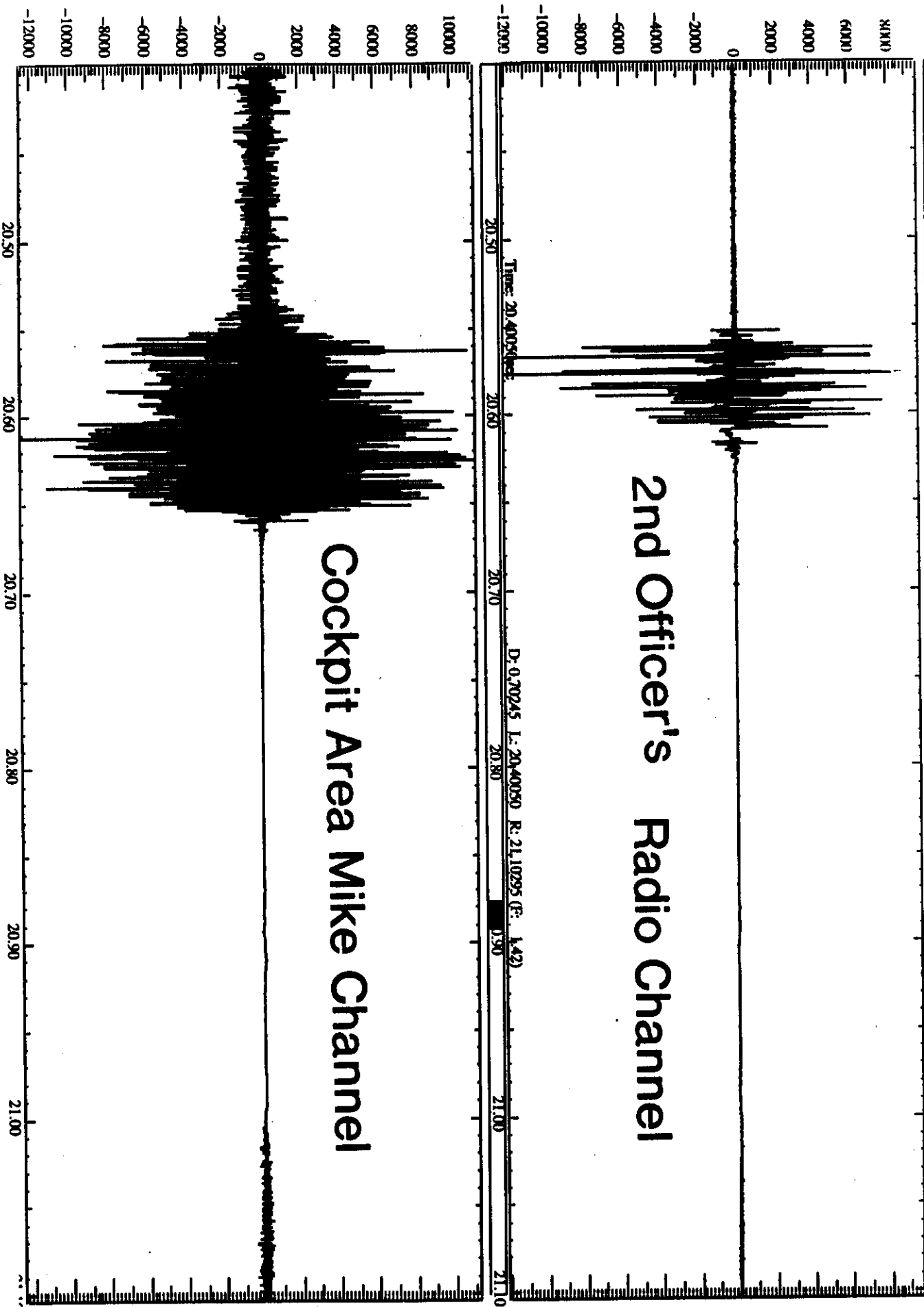
D: 0.70245 L: 20.40050 R: 21.10295 (F: 1.42)

2nd Officer's Radio Channel

Time: 20.40050sec

D: 0.70245 L: 20.40050 R: 21.10295 (F: 1.42)

Cockpit Area Mike Channel



Time: 3.49870sec

D: 2.00905 L: 3.49615 R: 5.50520 (F: 0.50)

1st Officer's Radio Channel

Time: 3.49870sec D: 2.00905 L: 3.49615 R: 5.50520 (F: 5080)

PanAm

Cockpit Area Microphone

Time: 3.49870sec D: 2.00905 L: 3.49615 R: 5.50520 (F: 0.50)

Captain's Radio Channel

Time: 3.49870sec

D: 2.00905 L: 3.49615 R: 5.50520 (F: 0.50)

2nd Officer's Radio Channel

Time: 3.49870sec D: 2.00905 L: 3.49615 R: 5.50520 (F: 0.50)

Time: 4.28655sec

D: 3.48835 L: 4.28280 R: 7.77115 (F: 0.29)

1st Officer's Radio Channel

Time: 4.28655sec

D: 3.48835 L: 4.28280 R: 7.77115 (F: 0.29)

Air India

Cockpit Area Microphone

Time: 4.28655sec

D: 3.48835 L: 4.28280 R: 7.77115 (F: 0.29)

Captain's Radio Channel

Time: 4.28655sec

D: 3.48835 L: 4.28280 R: 7.77115 (F: 0.29)

2nd Officer's Radio Channel

Time: 4.28655sec

D: 3.48835 L: 4.28280 R: 7.77115 (F: 0.29)

Time: 0.49830sec

D: 2.88840 L: 0.49830 R: 3.38670 (F: 0.35)

1st Officer's Radio Channel

Time: 0.49830sec

D: 2.88840 L: 0.49830 R: 3.38670 (F: 0.35)

Cockpit Area Microphone

Time: 0.49830sec

D: 2.88840 L: 0.49830 R: 3.38670 (F: 0.35)

Captain's Radio Channel

Time: 0.49830sec

D: 2.88840 L: 0.49830 R: 3.38670 (F: 0.35)

2nd Officer's Radio Channel

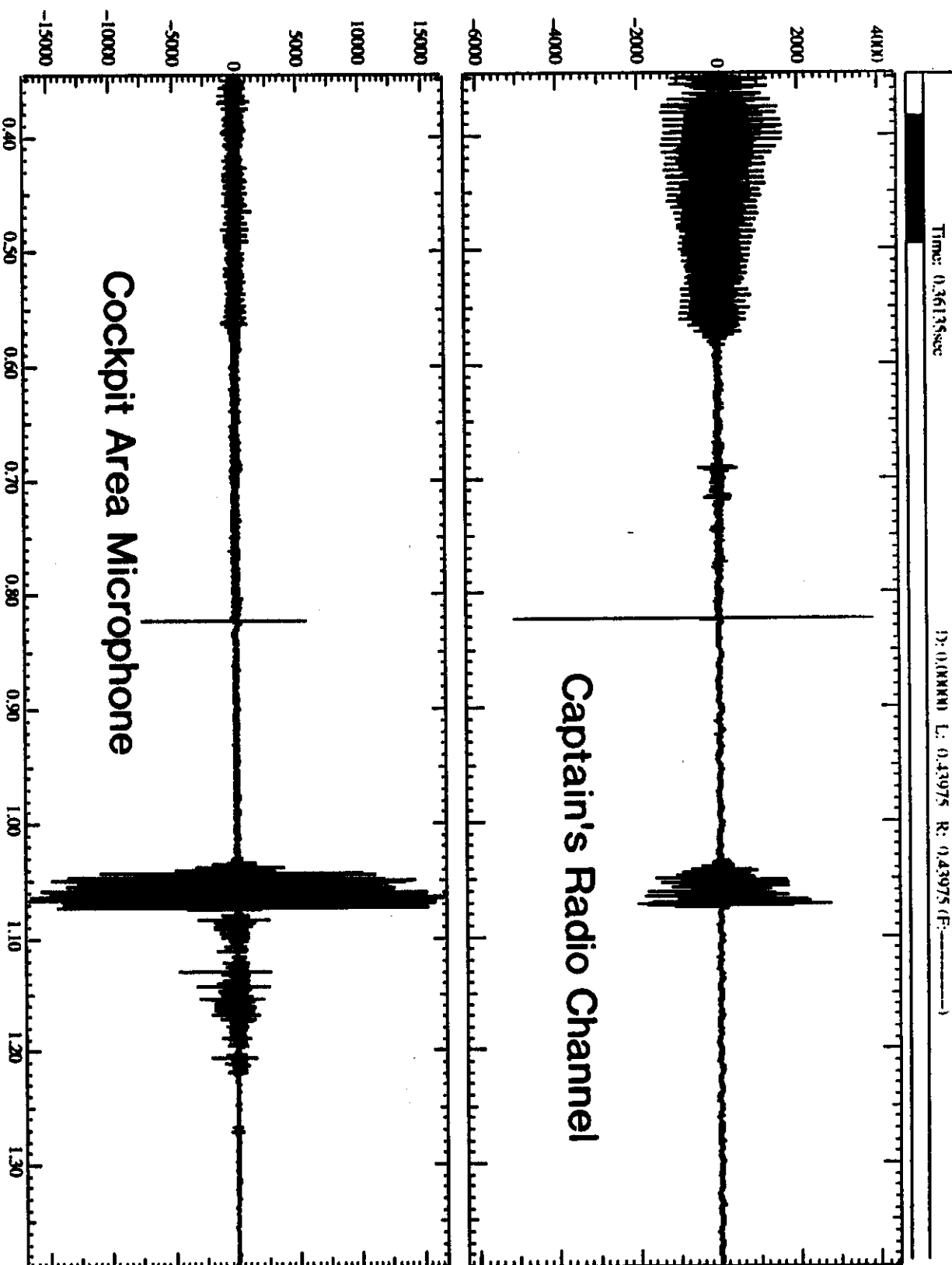
Time: 0.49830sec

D: 2.88840 L: 0.49830 R: 3.38670 (F: 0.35)

United

Time: 0.36135sec

D: 0.00000 L: 0.43975 R: 0.43975 (F:-----)



Philippine Air

Time: 19.06410sec

D: 2.00950 L: 0.00000 R: 2.00950 (E: 0.50)

TWA-800

Time: 5.60945sec D: 2.00950 L: 0.00000 R: 2.00950 (E: 0.50)

PanAm

Time: 6.61826sec D: 2.00950 L: 0.00000 R: 2.00950 (E: 0.50)

Air India

Time: 3.01015sec D: 2.00950 L: 0.00000 R: 2.00950 (E: 0.50)

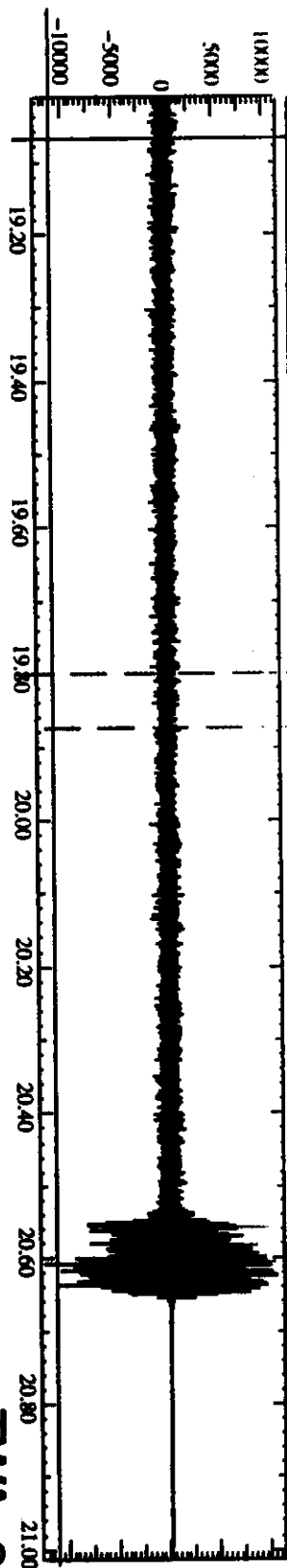
United

Time: 2.00950sec D: 2.00950 L: 0.00000 R: 2.00950 (E: 0.50)

Philippine Air

Time: 19.06910sec

D: 0.07400 L: 19.80200 R: 19.87600 (F: 13.51)

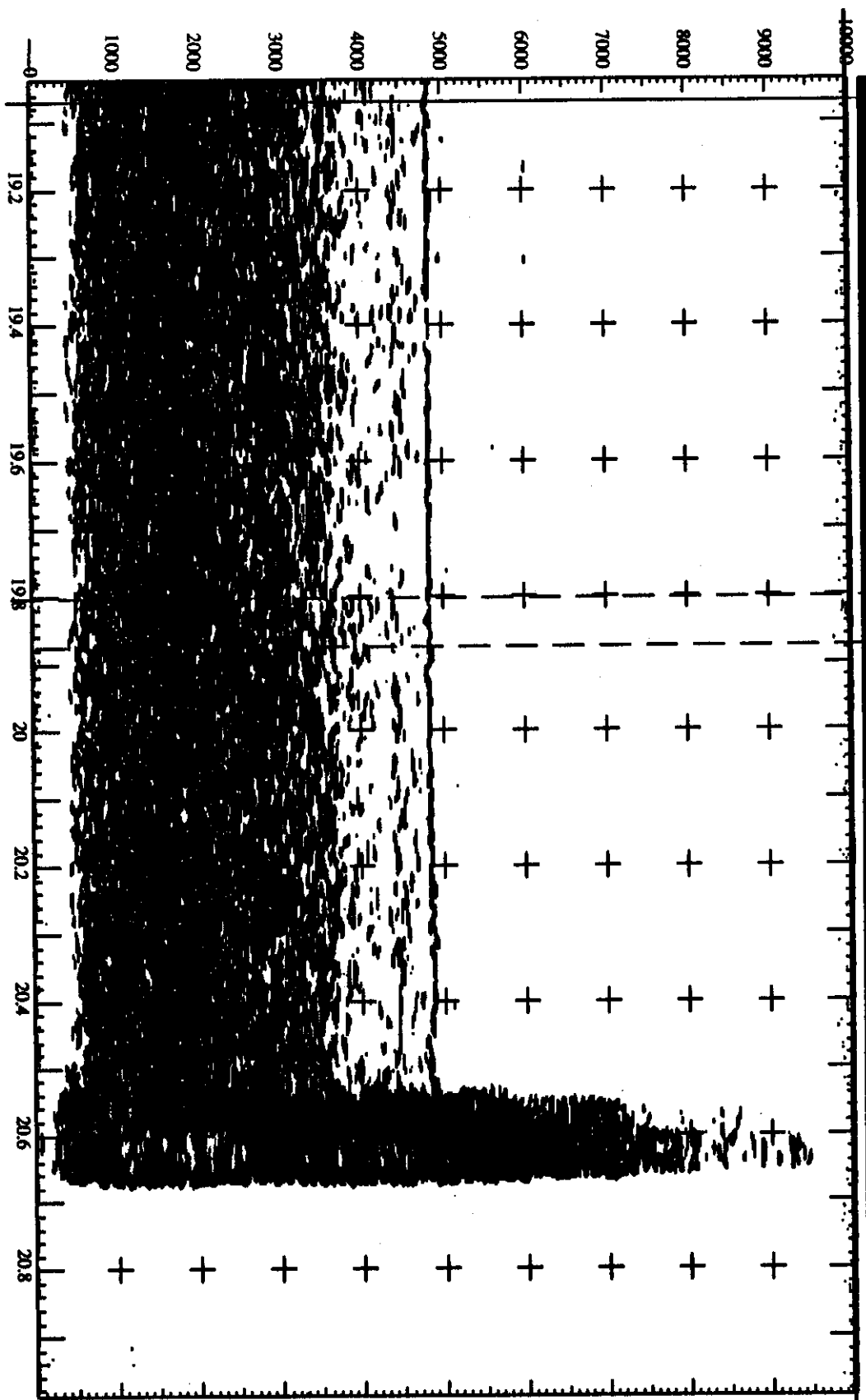


TWA-800

Time: 19.0691 Freq: 9980.81

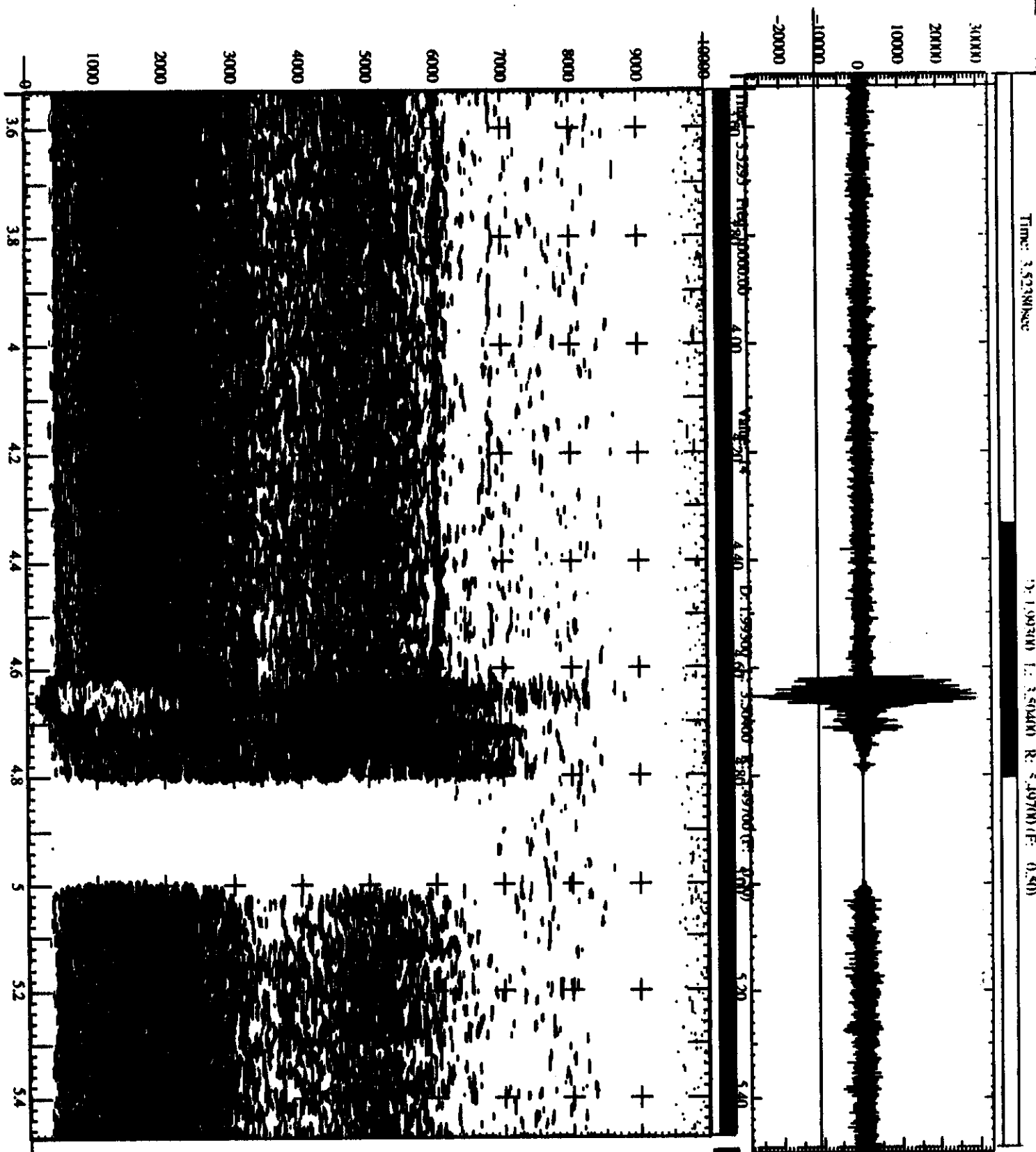
Value: 15

D: 0.07400 L: 19.80200 R: 19.87600 (F: 13.51)



TIME 3.523818sec

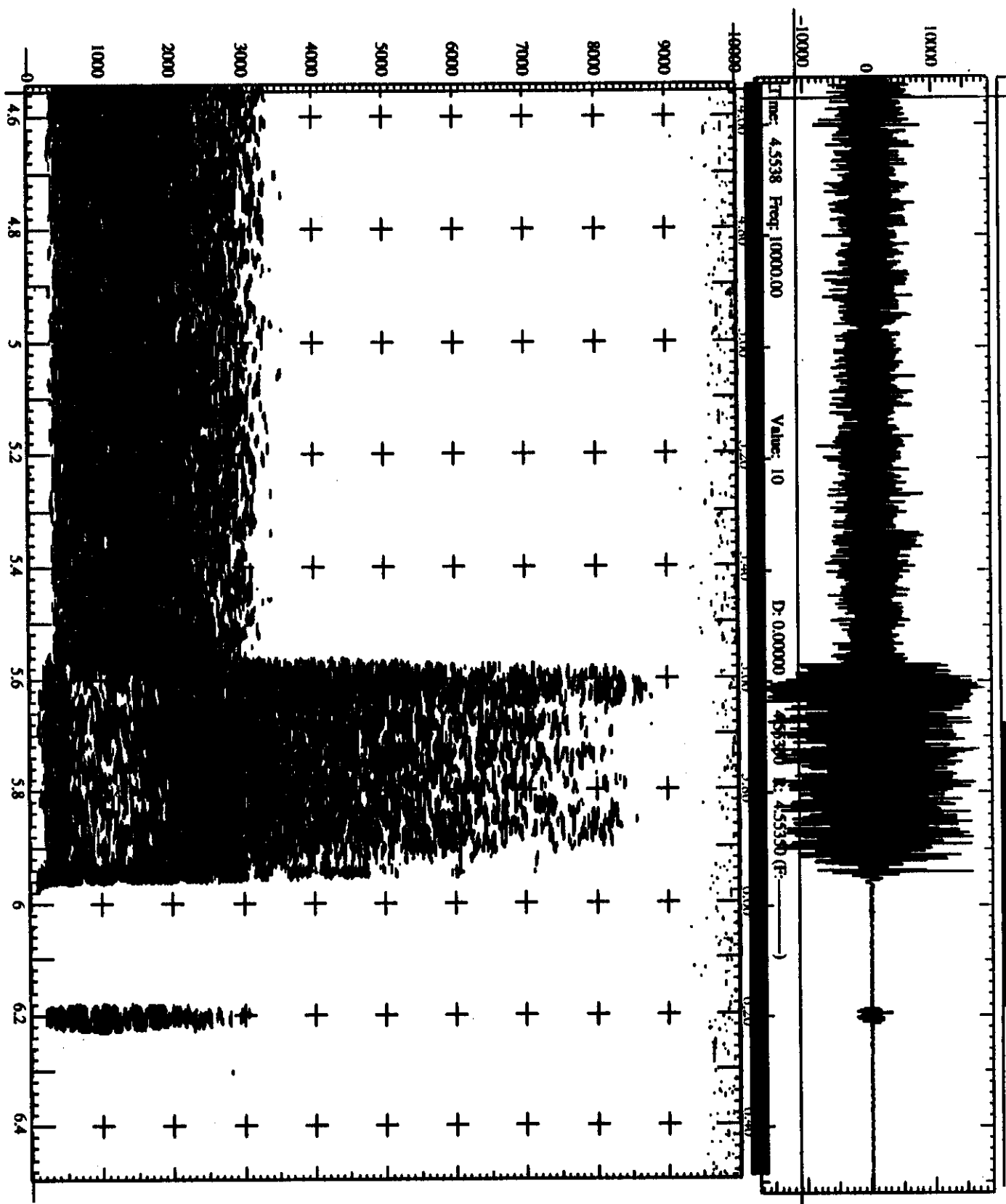
D: 1.09300 L: 3.50400 R: 5.49700 (E: 0.50)



PanAm

Time: 1.553400

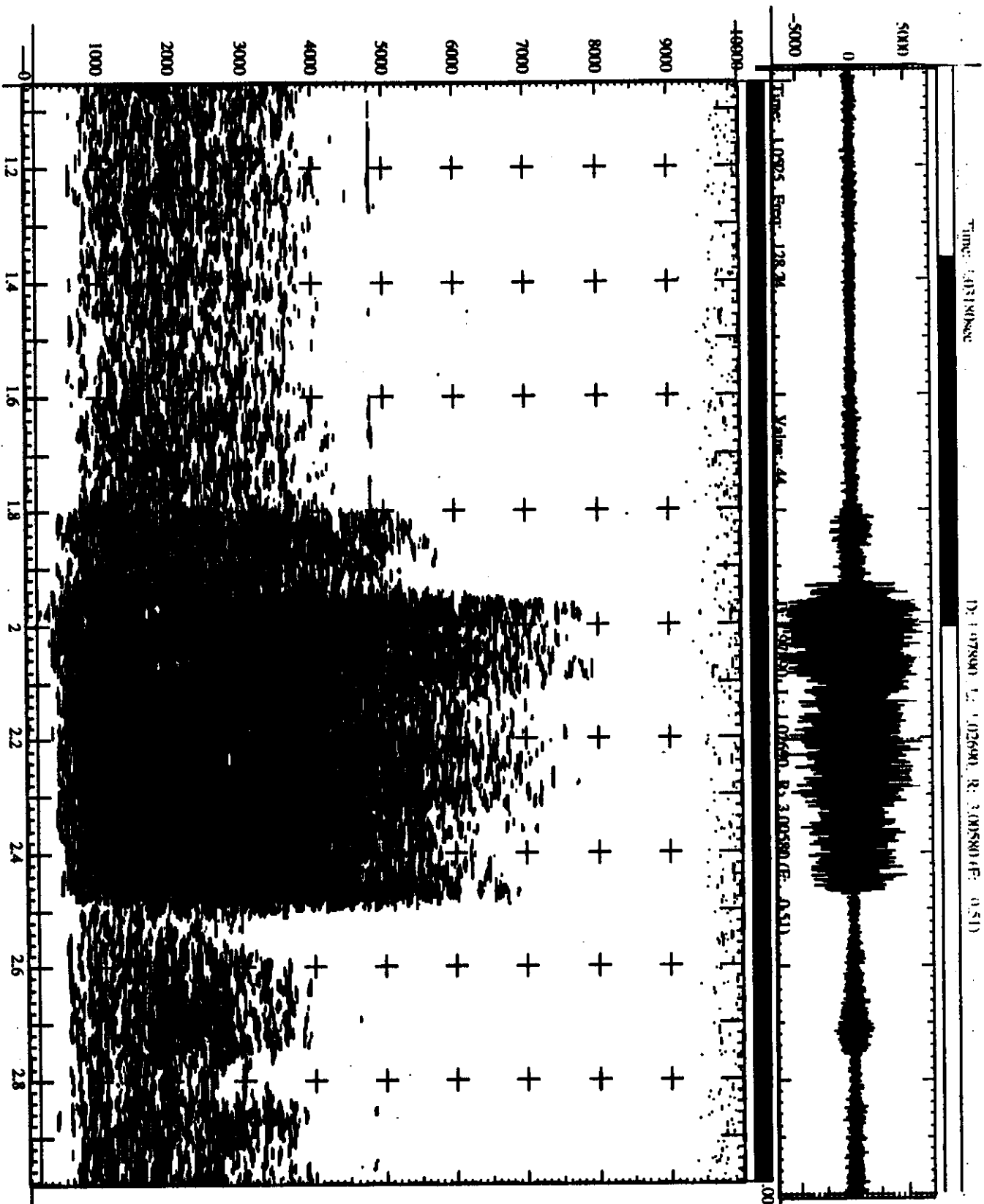
Value: 10 D: 0.00000



Air India

TIME: 1.071800

D: 1.07800 L: 1.02600 R: 3.00580 (E: 0.51)



United

Time: 0.55770sec

D: 0.67765 L: 0.53985 R: 1.21750 (F: 1.48)

Philippine Air

26

Time: 0.5654 Freq: 0.00

Value: 40

D: 0.67765 L: 0.53985 R: 1.21750 (F: 1.48)

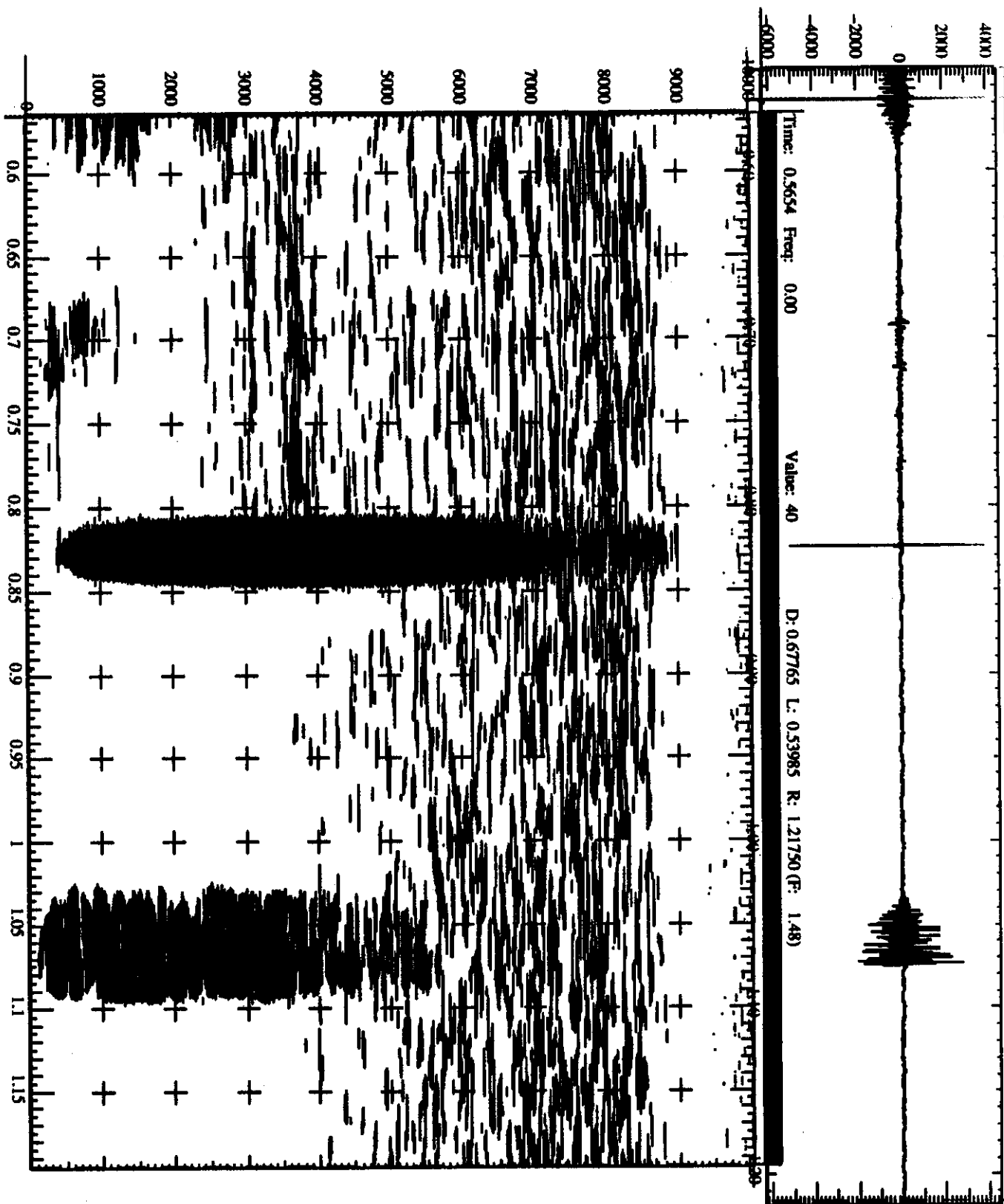


Chart 17

Time: 0.01020sec

D: 0.0000 L: 0.00525 R: 0.00525 (E: ———)

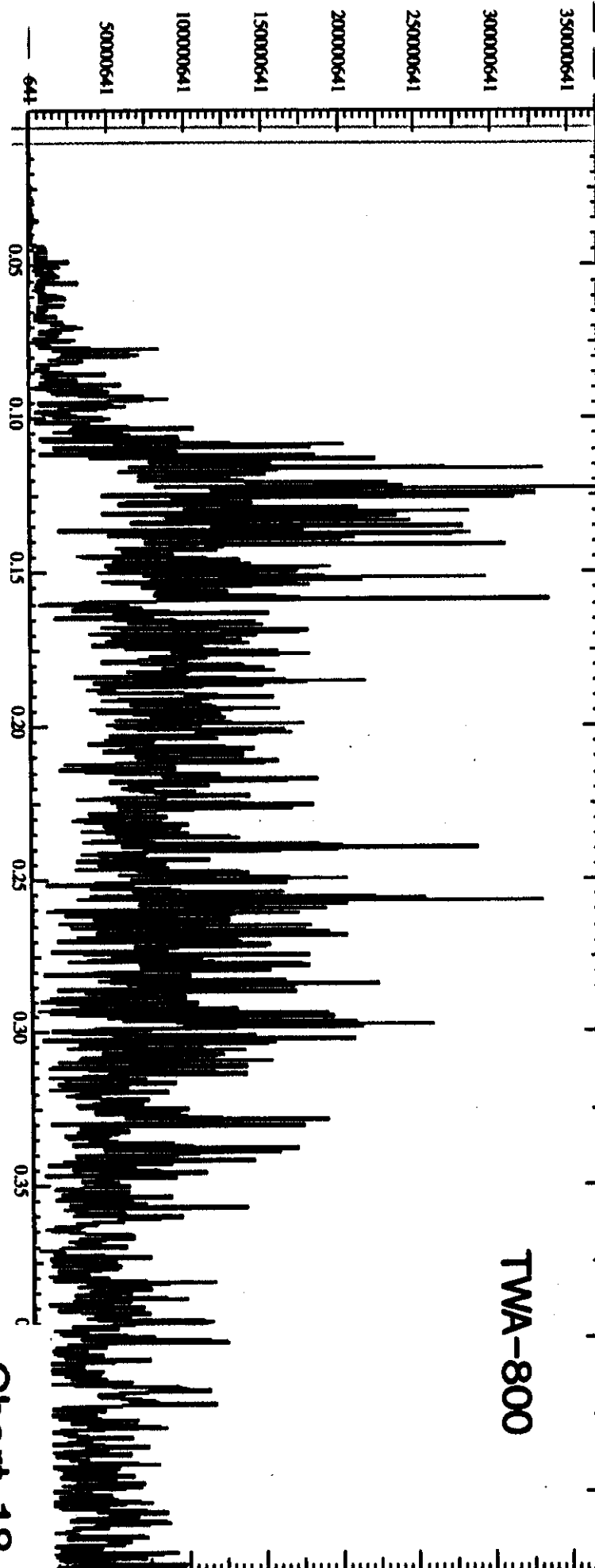
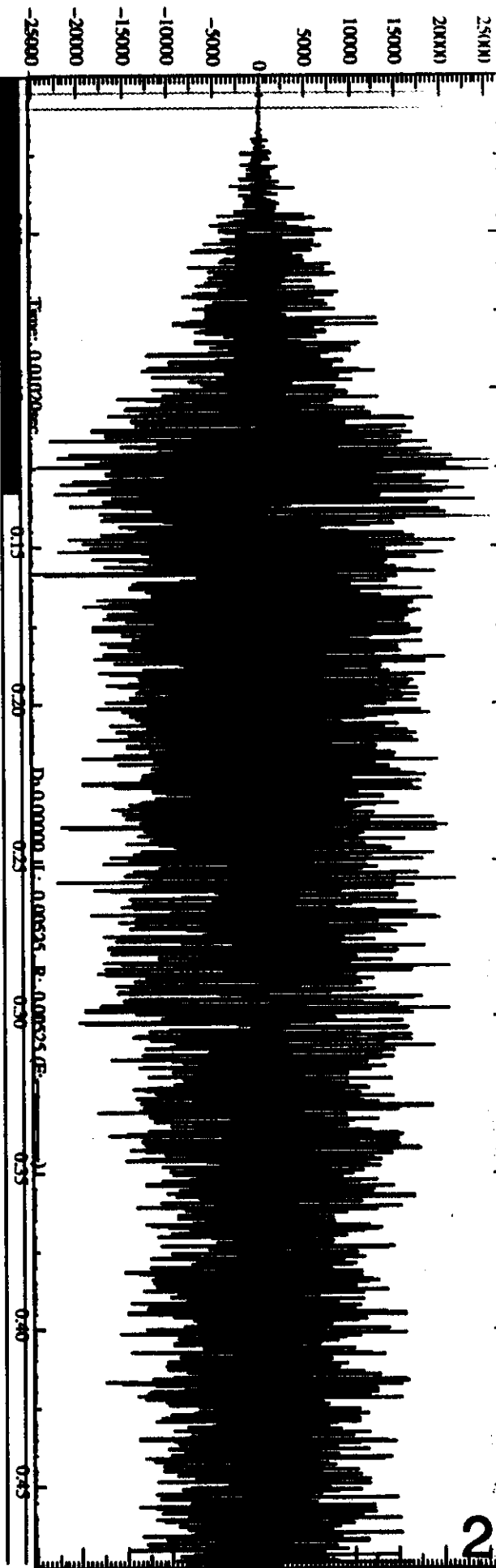
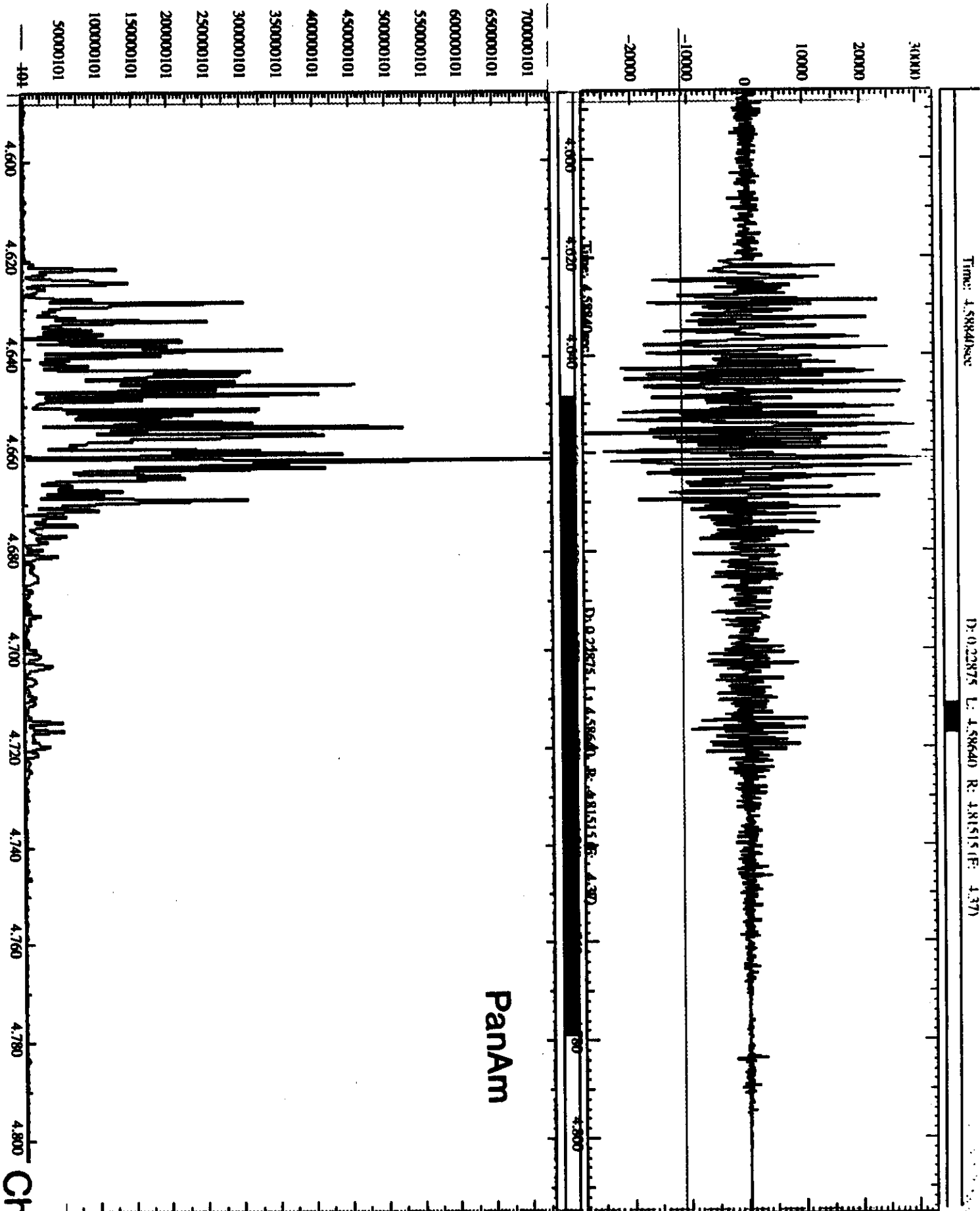


Chart 18

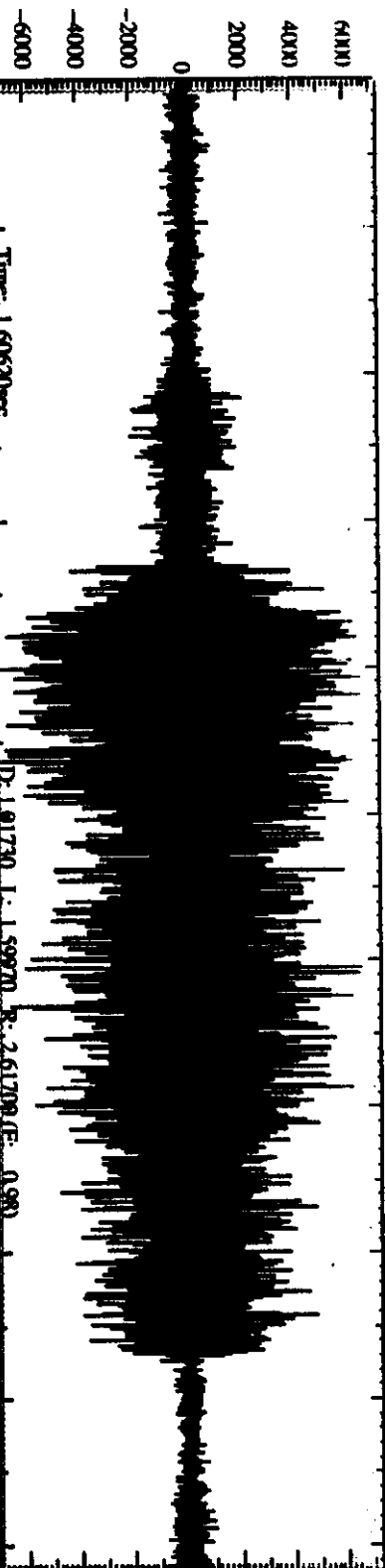
Time: 4.58840sec

D: 0.22875 L: 4.58640 R: 4.81515 (F: 4.37)



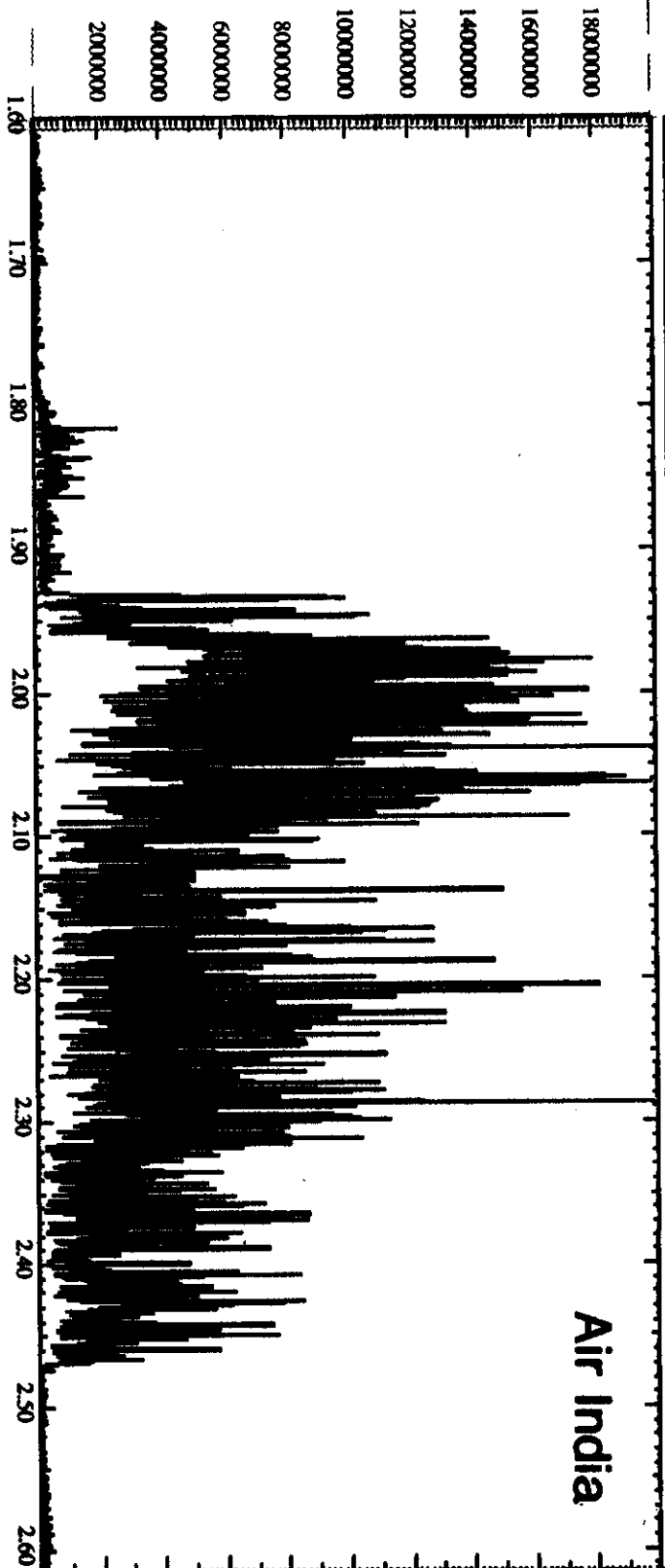
Time: 1.60620sec

D: 1.01730 L: 1.59270 R: 2.61700 (F: 0.98)



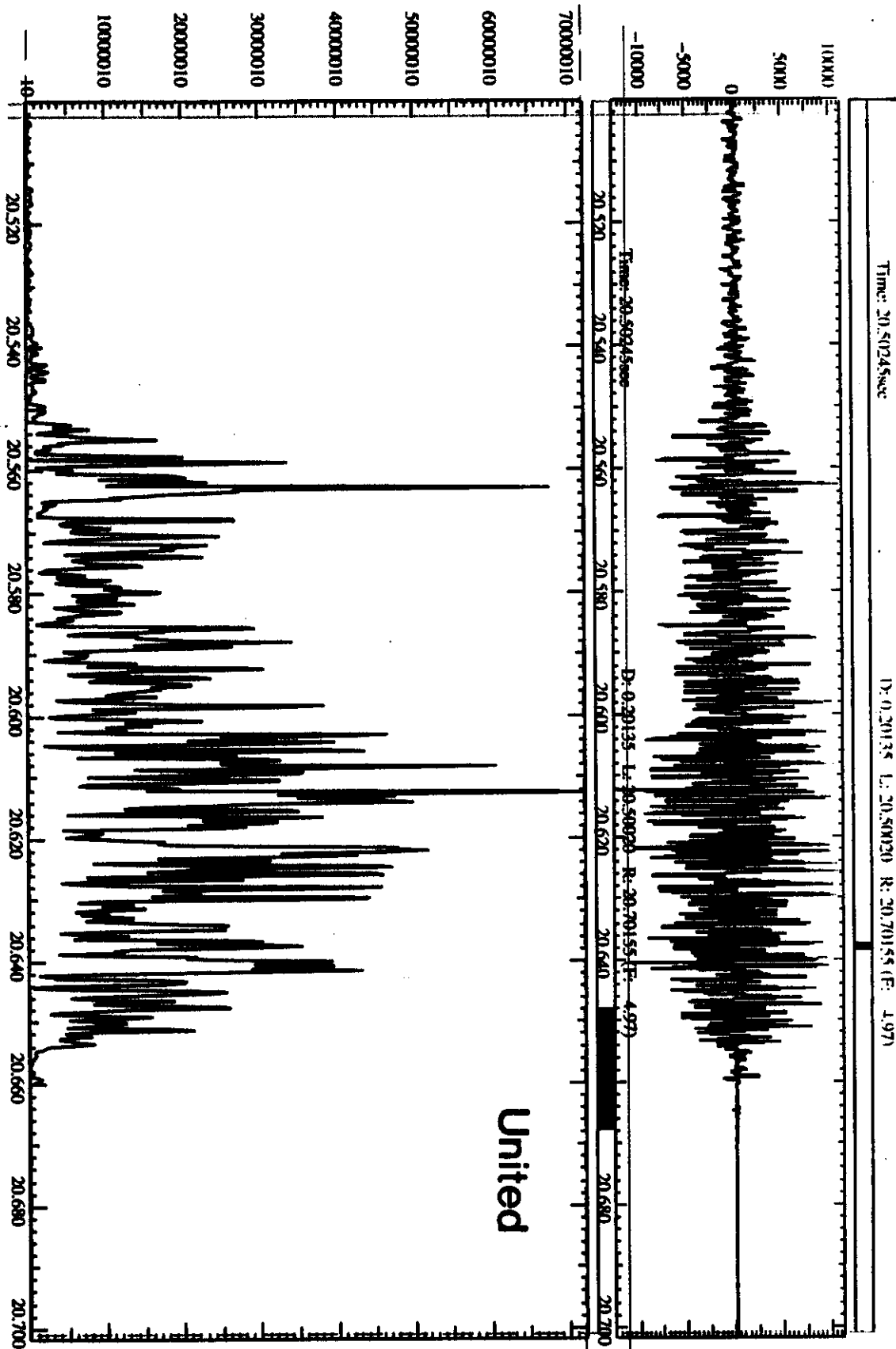
Time: 1.60620sec

D: 1.01730 L: 1.59270 R: 2.61700 (F: 0.98)



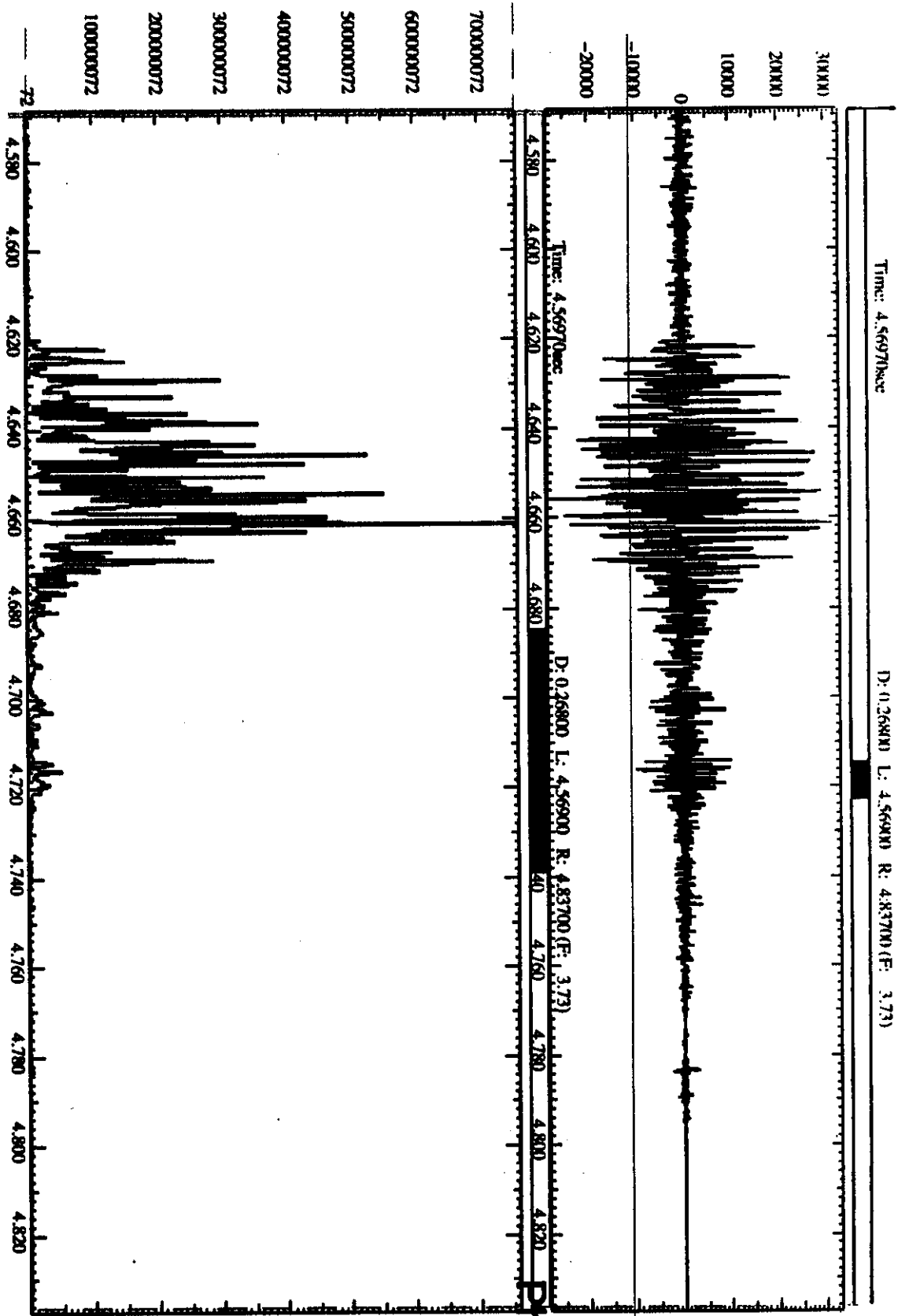
Time: 20.50245sec

D: 0.20135 L: 20.50020 R: 20.70155 (E: 4.97)



Time: 4.56970sec

D: 0.26800 L: 4.56900 R: 4.83700 (F: 3.73)



Philippine Air

Time: 0.02590sec

D: 0.00000 I: 0.02570 R: 0.02570 (F:)

Time of Det

Cockpit Pressure

Time: 0.02550sec

D: 0.00000 I: 0.02570 R: 0.02570 (F:)

Cockpit Acell

Time: 0.02530sec

D: 0.00000 I: 0.02570 R: 0.02570 (F:)

Cabin Acell

Time: 0.02550sec

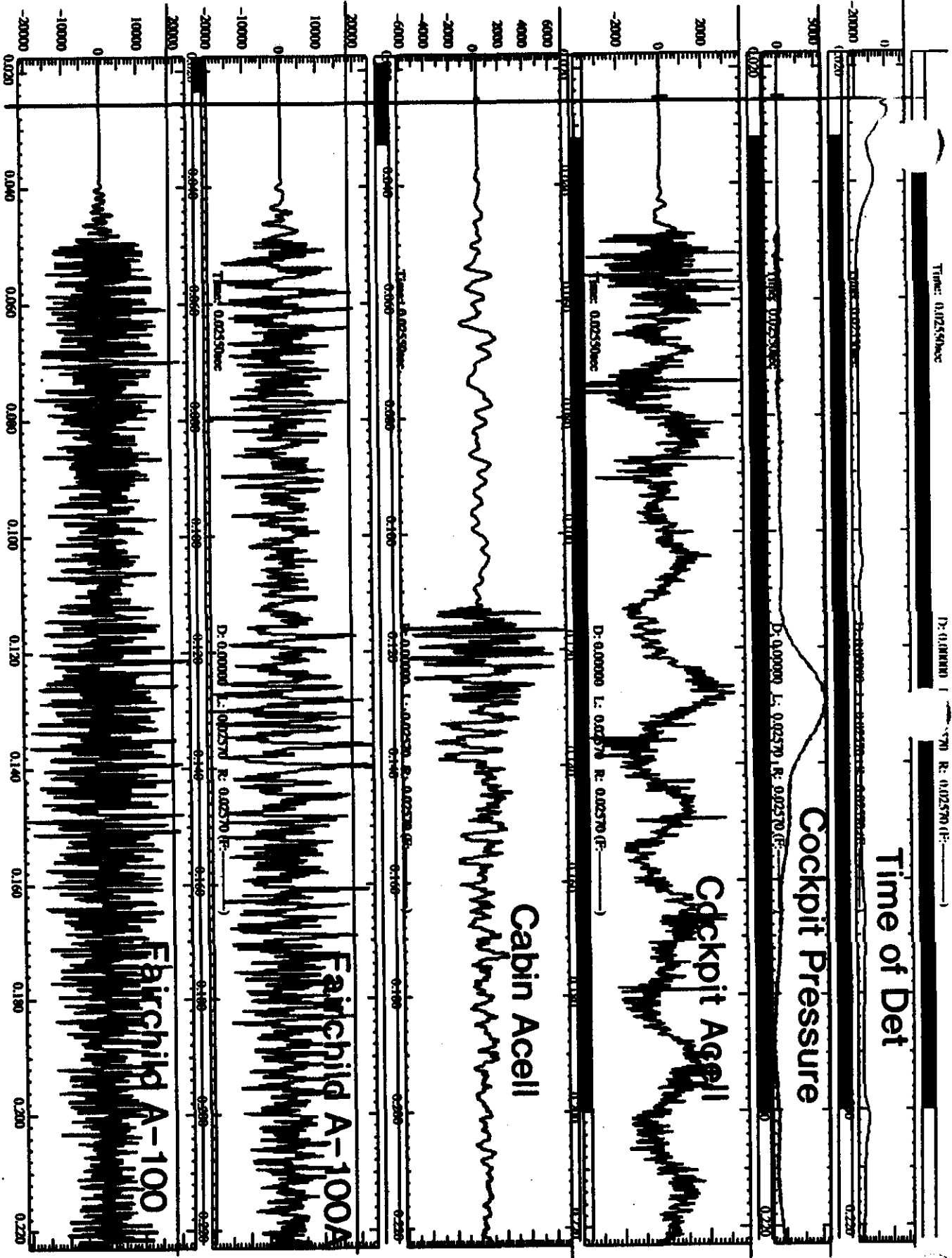
D: 0.00000 I: 0.02570 R: 0.02570 (F:)

Fairchild A-100A

Time: 0.02570sec

D: 0.00000 I: 0.02570 R: 0.02570 (F:)

Fairchild A-100H



Time: 0.02542sec

0.02542 R: 0.02542 (F)

Time of Det



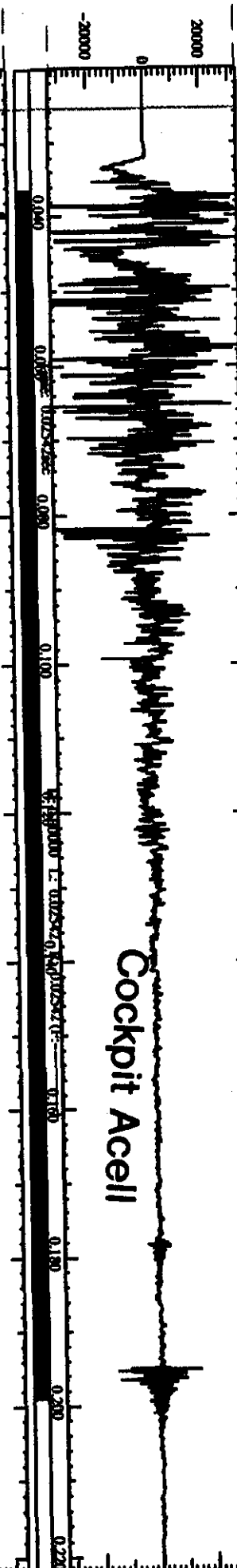
R: 0.025420 L: 0.025420 R: 0.02542 (F) 0.460 0.180 0.200 0.220

Cockpit Pressure



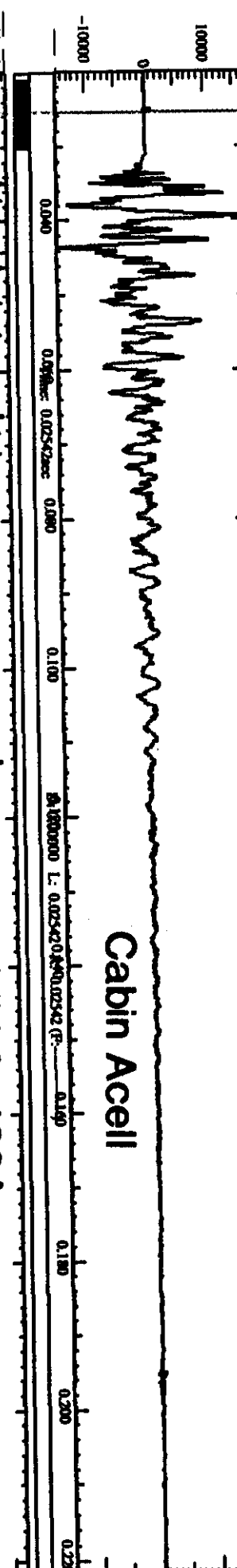
R: 0.025420 L: 0.025420 R: 0.02542 (F) 0.460 0.180 0.200 0.220

Cockpit Acell



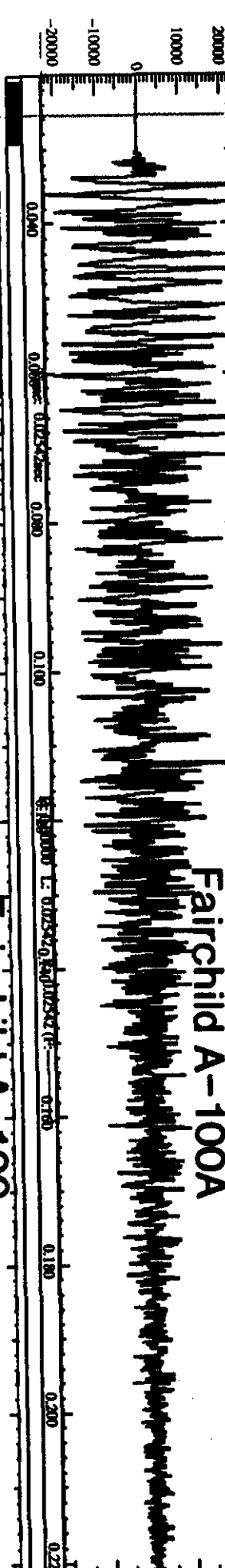
R: 0.025420 L: 0.025420 R: 0.02542 (F) 0.460 0.180 0.200 0.220

Cabin Acell



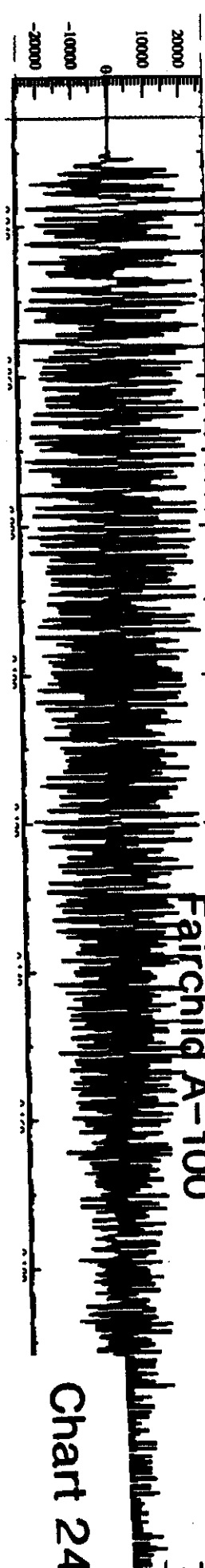
R: 0.025420 L: 0.025420 R: 0.02542 (F) 0.460 0.180 0.200 0.220

Fairchild A-100A



R: 0.025420 L: 0.025420 R: 0.02542 (F) 0.460 0.180 0.200 0.220

Fairchild A-100



Time: 0.02542sec

D: 0.00000 L: 0.02542 R: 0.02542 (F:)

Time of Det

Cockpit Pressure

Time: 0.02542sec

D: 0.00000 L: 0.02542 R: 0.02542 (F:)

Cockpit Accel

Time: 0.02542sec

D: 0.00000 L: 0.02542 R: 0.02542 (F:)

Cabin Accel

Time: 0.02542sec

D: 0.00000 L: 0.02542 R: 0.02542 (F:)

Fairchild A-100A

Time: 0.02542sec

D: 0.00000 L: 0.02542 R: 0.02542 (F:)

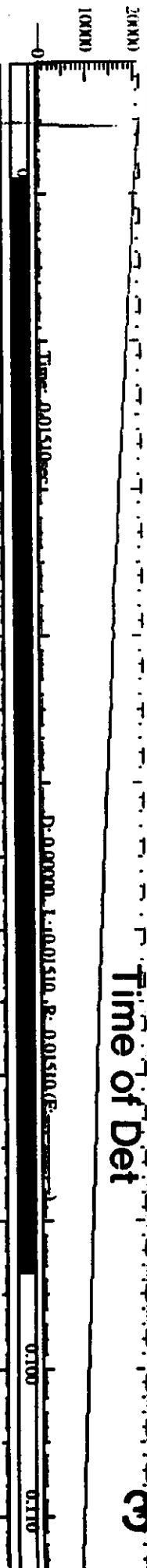
Fairchild A-100

Time: 0.02542sec

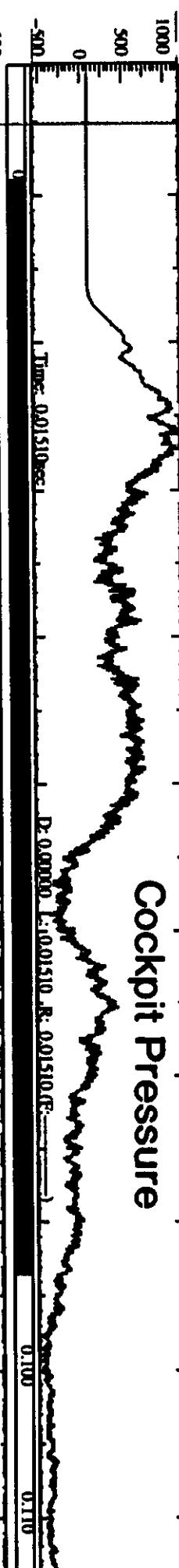
D: 0.00000 L: 0.02542 R: 0.02542 (F:)

Time of Det

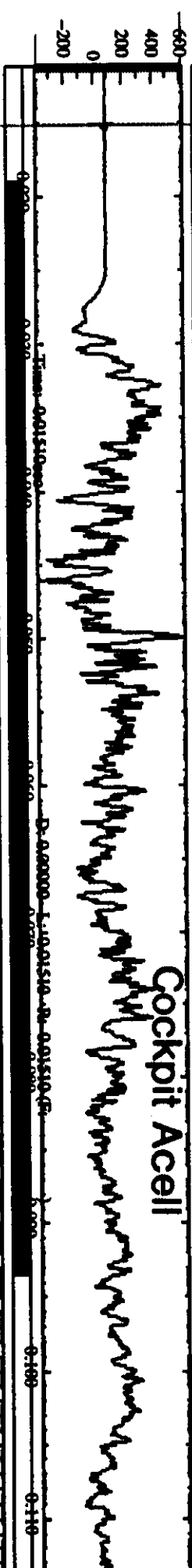
10
3



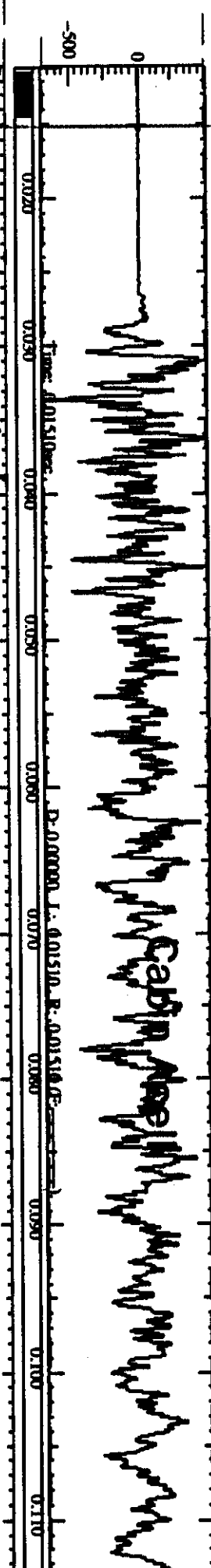
Cockpit Pressure



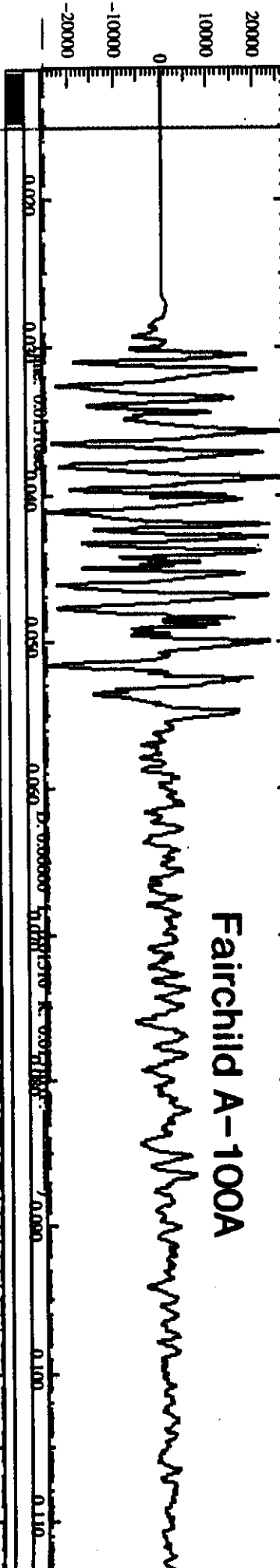
Cockpit Acell



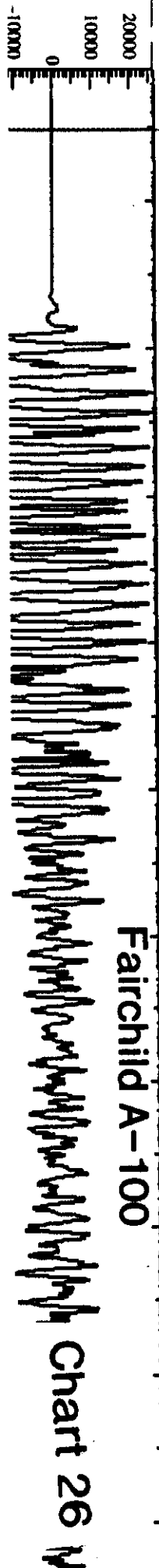
Cabin Acell



Fairchild A-100A



Fairchild A-100



12:00 (XXXX) 1: 0012704 2: 0012704 (F

36

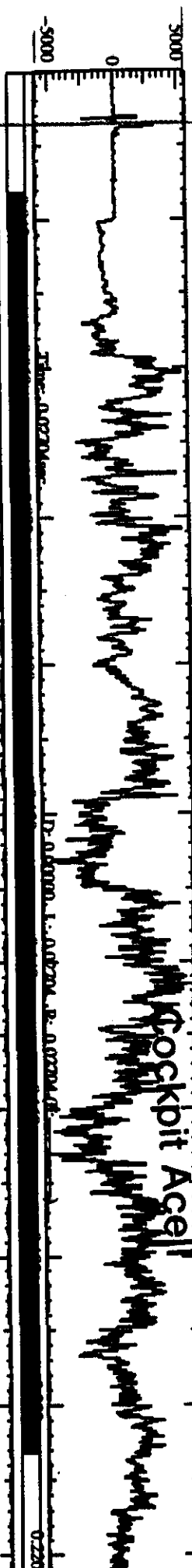
Time of Det



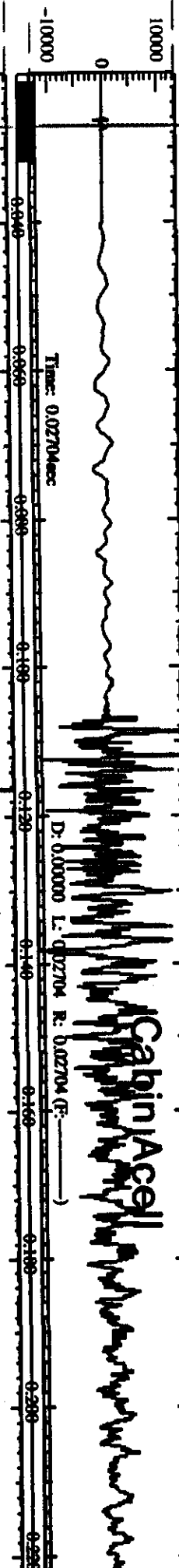
Cockpit Pressure



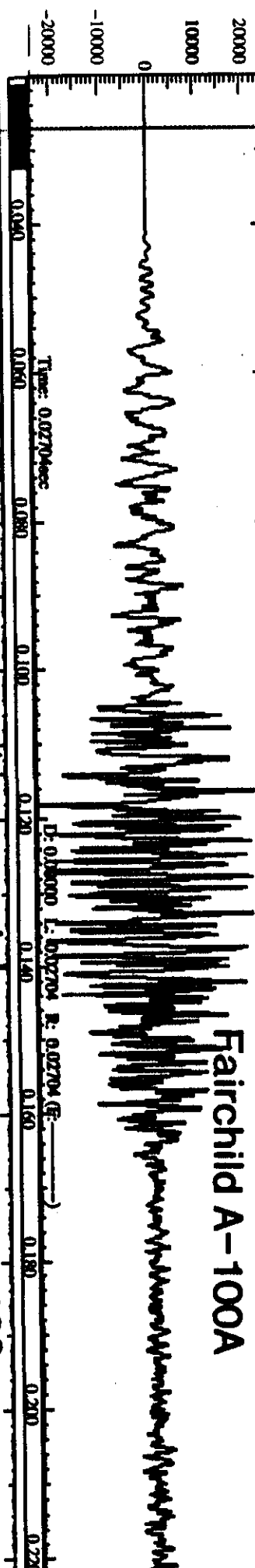
Rockpit Age



Cabin Ace



Fairchild A-100A



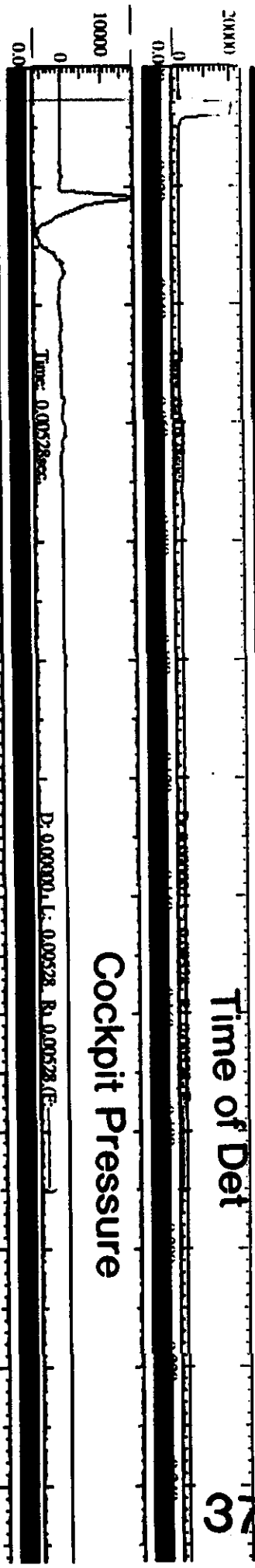
Fairchild A-100

Chart 27

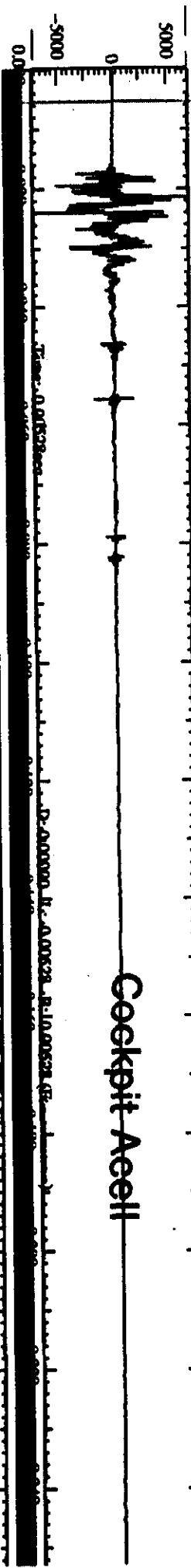
Time of Det

37

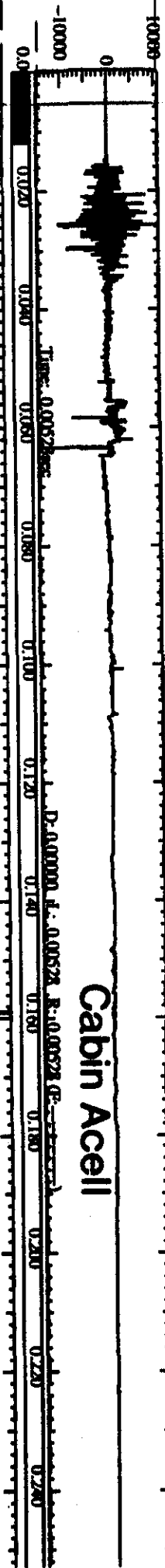
Cockpit Pressure



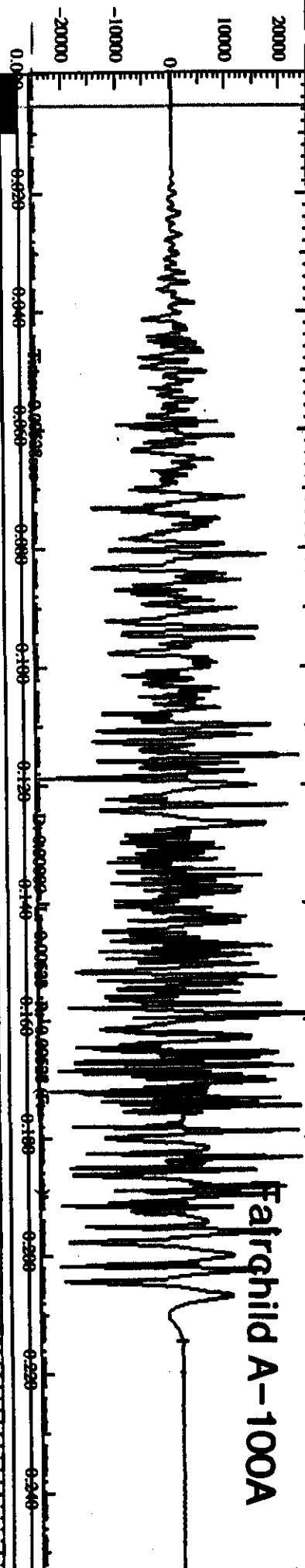
Cockpit Acell



Cabin Acell



Fairchild A-100A



Fairchild A-100

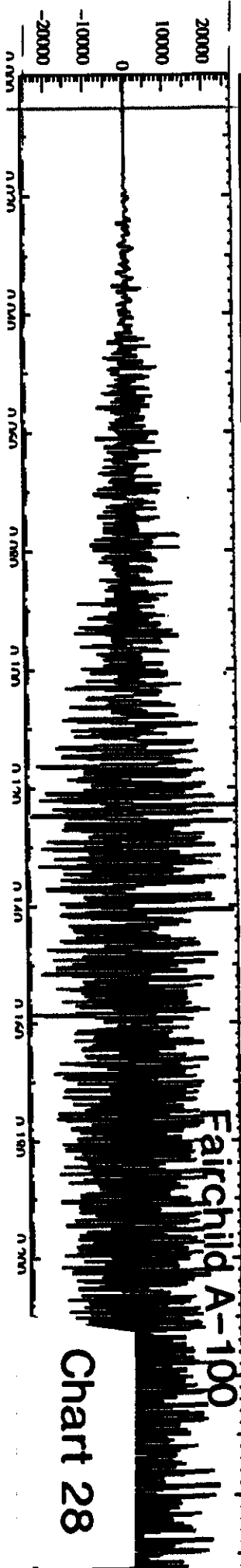
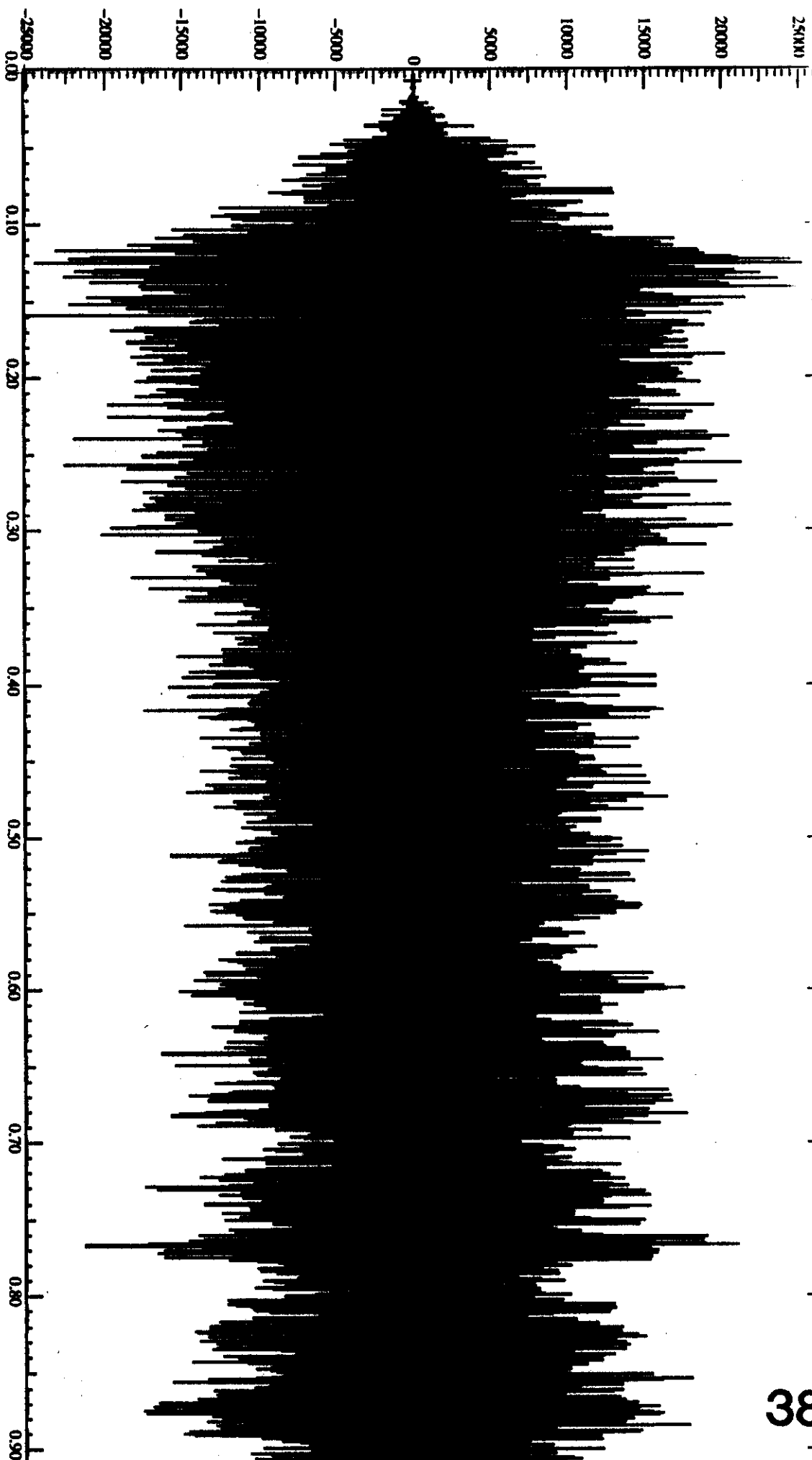
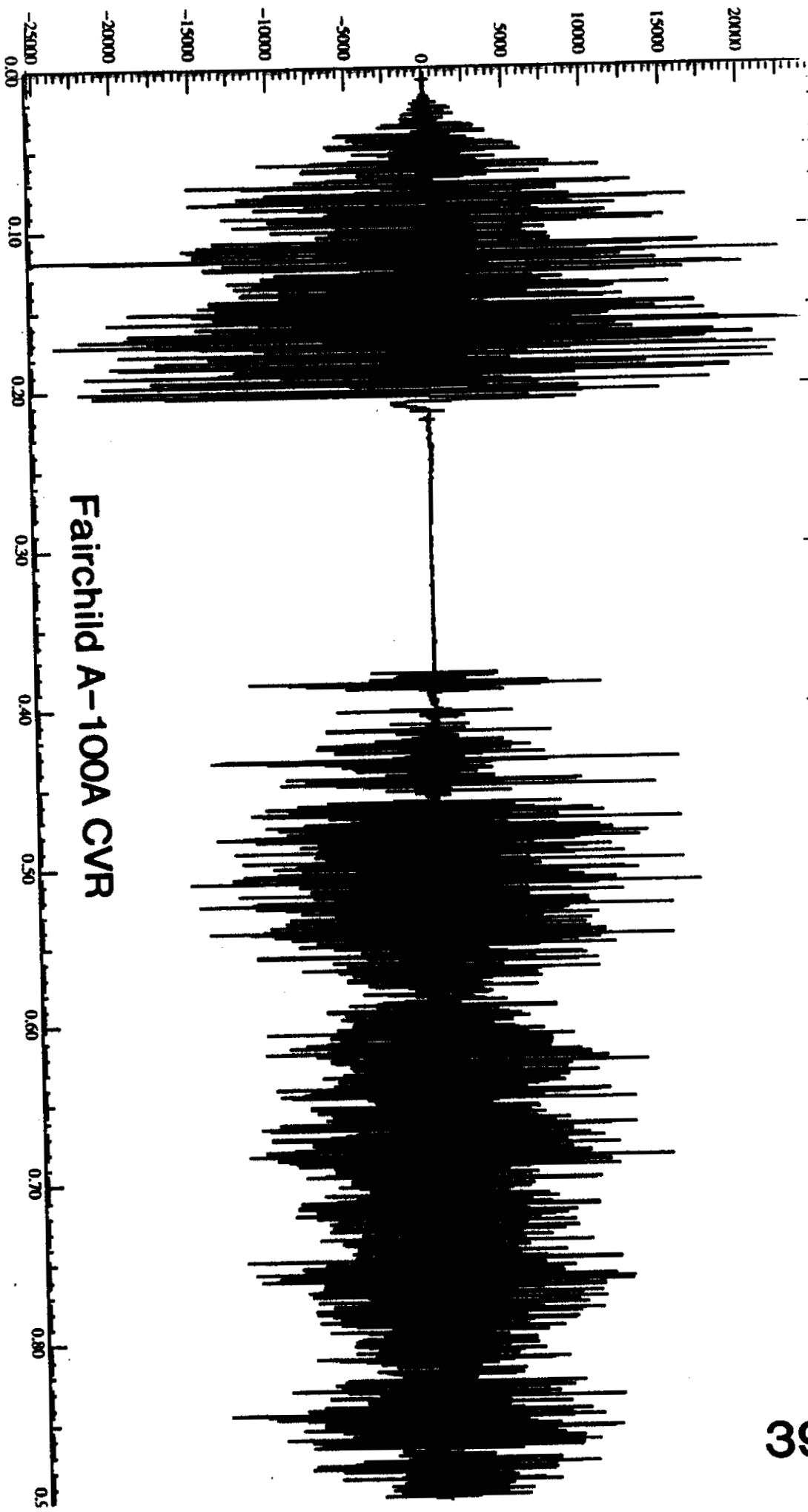


Chart 28



Fairchild A-100 CVR

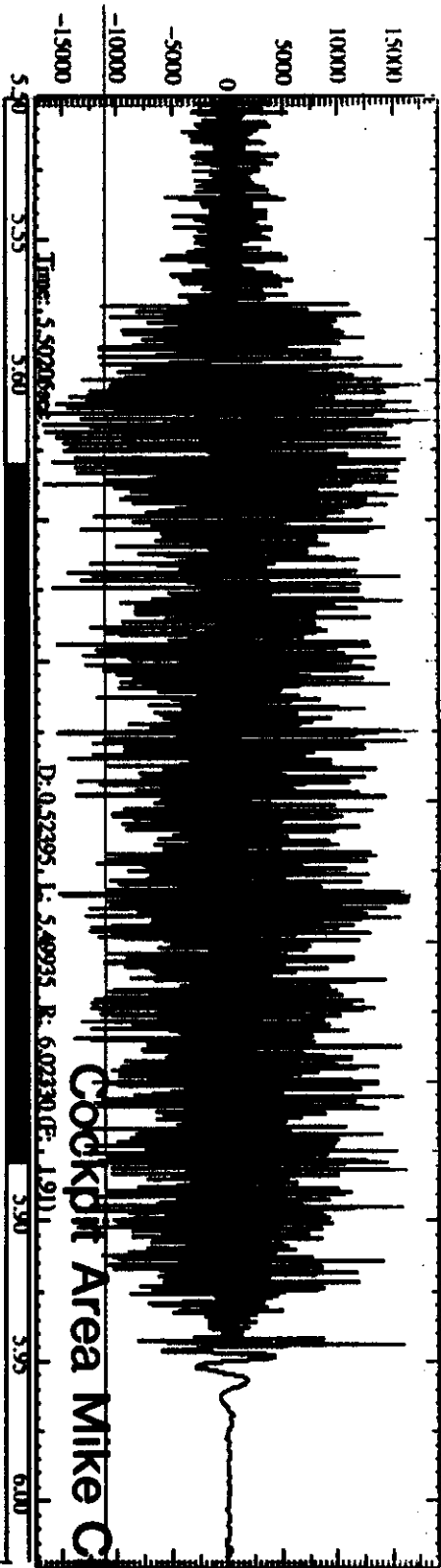
Chart 29



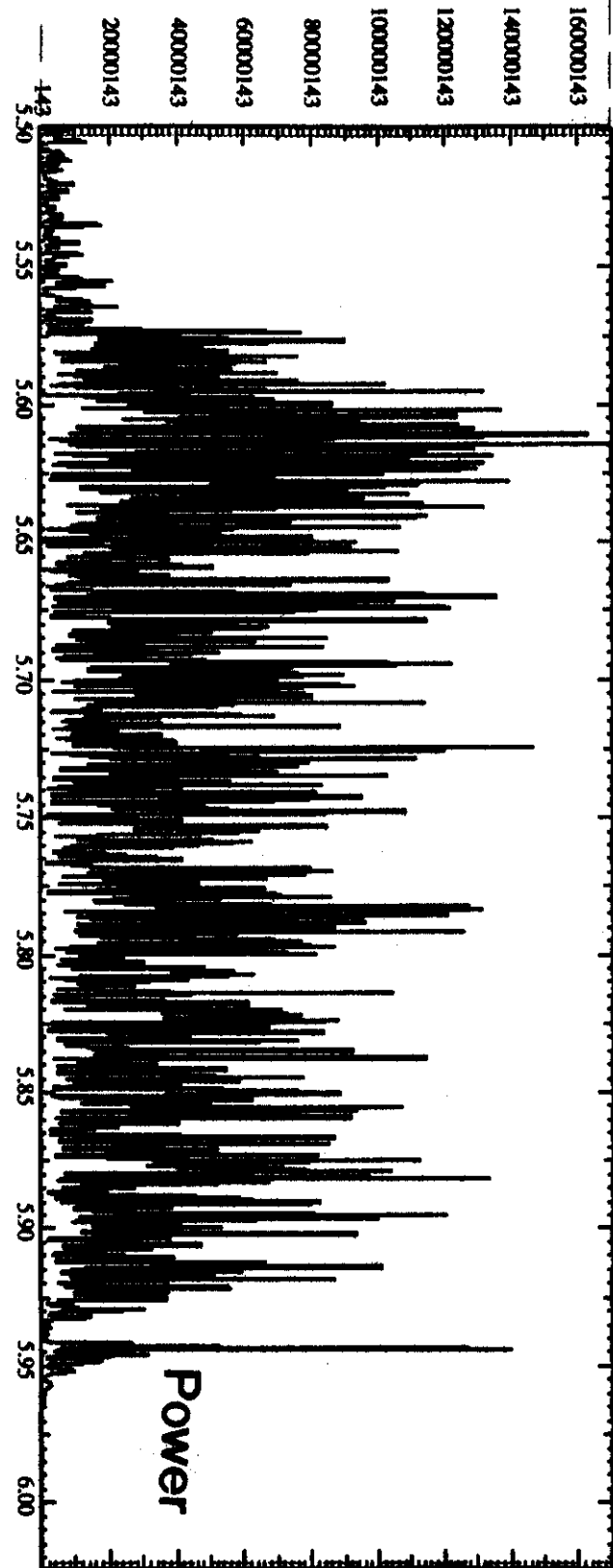
Fairchild A-100A CVR

Time: 5.51205sec

D: 0.52395 L: 5.49935 R: 6.02330 (E: 1.91)



Cockpit Area Mike Channel



Power